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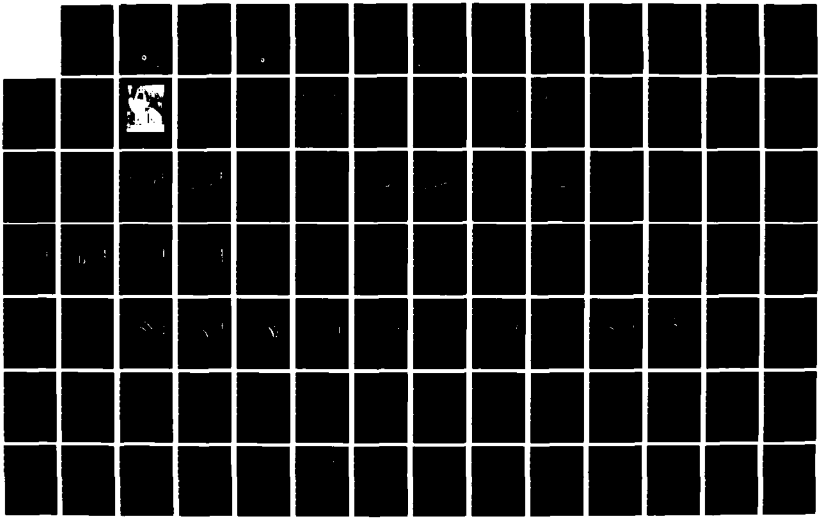

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THE PREDICTION OF THE STRENGTH AND NATURAL FREQUENCIES OF VIBRATION OF CFAV QUEST PROPELLERS NRC 45 AND NSMB 5363

D.R. Smith

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

Canada

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Approved by B.F. Peters A/Director/Technology Division

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ABSTRACT

The strength and vibration characteristics of the original NRC 45 and the new NSMB 5363 propellers for CFAV QUEST are predicted using the Finite Element Program PVAST. The static blade loadings for the analysis were produced with the M.I.T. Program PINV 4. Predictions are presented for stresses, static displacements, and natural frequencies of vibration for both propellers. Static stress results obtained using PVAST are shown to be in good agreement with those supplied by the Netherlands Ship Model Basin for the NSMB 5363 propellers.

Résumé

Les caractéristiques de résistance et de vibrations du NRC 45 original et des nouvelles hélices NSMB 5363 pour le CFAV QUEST sont prédites à l'aide du "Finite Element Program PVAST". Les essais de charge statique sur les pales nécessaires aux analyses ont été faits à l'aide du programme PINV 4 du M.I.T. Les prédictions portaient sur la résistance aux contraintes, les déplacements statiques et les fréquences naturelles de vibrations des deux hélices. Les résultats des essais de charge statique obtenus à l'aide du PVAST sont comparables à ceux obtenus par le "Netherlands Ship Model Basin" pour les hélices NSMB 5363.

TABLE OF CONTENTS

1. INTRODUCTION

The Defence Research Establishment Atlantic's (DREA) research vessel CFAV QUEST (Figure 1) was designed for quiet operation to permit scientific studies of underwater acoustics. Recent trends in this research have led to a requirement for a further reduction in the ship's underwater self-noise. The major sources of this noise are the ship's propellers. Consequently, a new set of propellers has been designed, which have superior performance in terms of noise and comparable performance in terms of efficiency.

As part of the verification process of this new design, the original and new propellers have been analysed to determine their structural strengths and natural frequencies of vibration. This Technical Memorandum describes the analysis of the QUEST propellers, which employed the finite element program PVAST,[1] and compares the results with those obtained by the Netherlands Ship Model Basin with the finite element program NASTRAN. PVAST was developed at DREA to carry out comprehensive structural analyses of modern marine propellers whose geometries are sufficiently complex that traditional analysis methods[2,3] are no longer useful.

2. PROPELLER GEOMETRY

The new propeller design has involved considerable changes to the geometrical characteristics of the original propellers in order to achieve the improved performance. The most significant change has been to the blade skew, as illustrated in a comparison of Figures 2 and 3, which show the old and new propellers, respectively.

The original propeller (NRC 45) designed by the National Research Council of Canada, using English units, is shown in common naval architectural format in Figure 4. It has long narrow blades which are raked 15 degrees aft. In addition, a slight amount of skew has been added. Separate drawings of the transverse and longitudinal views are shown in Figures 5 and 6. The drawings are based on a three-dimensional right handed axis system with Z, the axis of propeller rotation, positive aft and the X axis positive to starboard. The transverse view, which is often referred to as the projected outline, is the projection of a single blade on the XY plane normal to the propeller axis when looking forward. This view is used later in the report for showing blade surface stresses in the form of stress contours and vibratory mode shapes in the form of displacement contours. The longitudinal view, Figure 6, is the blade projection on the ZY plane. It shows the outline of the blade, when viewed from starboard.

The new propeller design (NSMB 5363) is the result of a joint effort by the Netherlands Ship Model Basin (NSMB) and DREA. The geometry described in S.I. units is shown in Figures 7 to 9. The blade is highly skewed with 15 degrees forward rake imposed to reduce the influence of skew induced rake on the total net rake. The resulting net rake, which is approximately 16° aft, is shown in Figure 10 by the maximum thickness plot.

The blade tip outline for this propeller as well as for propeller NRC 45 was not adequately described for computer plotting. This is not unusual and a special routine has been developed in the propeller geometry program BLADGM[4] for generating this data for finite element analysis. The program also has the ability to generate tip profile data as shown in Figures 10, 11 and 12. Figure 10 is the maximum blade thickness diagram for the NSMB 5363 propeller. The tip profile shown on this drawing has been expanded in Figure 11 to show the detail. The generated extra blade sections for the profile are shown in Figure 12.

3. FINITE ELEMENT PROGRAM

The finite element program PVAST has been developed with special pre and post-processors for propeller analysis. The pre-processors automatically generate finite element grids for specified propeller geometry. Pressure loads are entered at any chosen radii and the program automatically generates the finite element nodal values as consistent load vectors by interpolation. Centrifugal effects in the form of body forces are calculated when the rotation rate is specified.

The program prepares for the calculation of natural frequencies and dynamic response by generating a consistent mass matrix for the blade. It also generates a finite element model to represent the mass of water surrounding a blade. This mass is added to the material mass of the blades and is concentrated at the nodes. The pre-processed data is then passed to the basic program for the calculation of deflections, stresses, natural frequencies of vibration, and when unsteady loads have been applied, the dynamic response.

The displacements, stresses and vibration results are then post-processed and displayed in graphic form as displacements, stress and vibratory mode shape contours and plots of chordwise stress distributions.

4. BLADE LOADING

The propellers have been analyzed for static hydrodynamic pressure loads only, as loads due to unsteady flow were not available. The pressures were obtained by the use of the MIT blade loading analysis program PINV-4,[5] and are shown in abbreviated form for clarity as chordwise distributions at fractions of the full propeller radius in Figures 13 and 14 for the back and face of the NRC 45 blade. The pressures were interpolated by PVAST to obtain the values (Figures 15 and 16) required for the fractions of the full blade radius specified for the finite element grid.

The pressure distributions for the NSMB 5363 blade generated by PINV-4 are shown in Figures 17 and 18. The very steep leading and trailing edge pressure peaks similar to those shown for the NRC 45 blade in Figures 13 and 14 have been adjusted. In this manner it was possible to avoid the use of narrow curved elements at the leading and trailing edges of the finite element grid to model the pressure distribution. The adjustment thus allowed the use of better proportioned elements

especially at the trailing edge, which is a critical region for the NSMB blade. The adjustment produced negligible effect on the blade forces as the pressure acted over a very small area. It was not applied to the NRC 45 blade loading as the blade was essentially unskewed and fairly symmetrical. The blade was therefore more tolerant to the use of narrow elements at the leading and trailing edges, since the elements remained nearly rectangular in form.

The pressure distributions applied to the 5363 propeller grid by the PVAST program are shown in Figures 19 and 20. the program smooths the data to fit the chordwise grid spacing. Using these figures, it is possible to check whether the grid spacing produces a pressure loading distribution which adequately represents the predicted loading from PINV4 shown in Figures 17 and 18.

Centrifugal loads due to propeller rotation were applied alone and in combination with the pressure loads. The centrifugal loads were treated as static body forces concentrated at the nodal points. The following rotational speeds, which were used in the analysis, correspond to the maximum operational condition for each propeller.

NRC 45	- 147 RPM
NSMB 5363 propeller	- 143 RPM

5. MATERIAL PROPERTIES

The same material properties were assumed for both propellers. The material is CUNIAL[6] bronze with the following properties:

Mechanical Properties

modulus of elasticity	18.5×10^6 psi
modulus of rigidity	$7.1\ 10^6$ psi
Poisson's ratio	.30
Brinell hardness	165
0.2% yield strength	39,780 psi
tensile strength	93,720 psi
percentage elongation	20%
corrosion fatigue strength	
@ 10^8 cycles	22,000 psi

Physical Properties

linear coefficient of expansion	$16. \times 10^{-6}$ in/in°C
specific weight	7.6
weight density	.275 lb/in^3
mass density	.000712 slugs/in^3

Composition	Percent
aluminum	9.3
manganese	1.0
iron	4.5
nickel	4.5
copper	80.0

6. FINITE ELEMENT MODELS

The blades were modelled using a thick/thin superparametric shell element (Figure 21(a) and 21(b)) with five degrees of freedom per node in the form of three translations and two rotations. The blade model includes the fillet radius at the junction between the blade and hub. A single radius at each grid chord station was used to approximate the compound radii actually specified for the blade.

The propeller was not modelled below the blade fillet in keeping with the model used by NSMB. The nodal points at the base of the fillets had their five degrees of freedom restricted creating the positive definite system required for the analysis.

The finite element model for the original propeller, NRC 45, is shown in Figure 21(c) and the model for the new propeller, NSMB 5363, is shown in Figure 22. A finer chordwise grid was chosen for the NSMB 5363 model to make it consistent with that chosen by the Netherlands Ship Model Basin[7], for later comparison of results.

Fluid mass models representing the water surrounding the blades were included for the vibration analyses. As only the first seven frequencies were to be extracted, a model coarser than the stress model was used. Figure 23 shows the coarse grid arrangement of the top layer of fluid elements surrounding the blade. Figure 24 is an isometric view of the complete fluid model showing the full six layers. The fluid model for propeller NSMB 5363 is shown in Figures 25 and 26.

7. BLADE STATIC STRESSES

The results of the static stress analyses are presented as constant principal stress contours drawn on the transverse projection of each type of blade. For convenience, the transverse projection looking from the stern was used for displaying both the face and back contours. The stress contours are presented on four diagrams for each blade type. The primary and secondary principal stress contours are given for both the face and back of the original and new blades. The primary stress is defined as the largest algebraic principal stress on the specified surface. The secondary principal stresses are orthogonal to the primary principal stresses.

7.1 Propeller NRC 45

The primary principal stress contours for the back of the NRC 45 blade, due to combined centrifugal and pressure loads, are shown on the transverse view in

Figure 27. The maximum stress is 5000 psi at contour 13 at the trailing edge. The secondary principal stresses under the same loading condition are shown in Figure 28 with a compressive stress of -7000 psi occurring at contour 1 towards mid chord at approximately 0.42 of the full radius.

The primary and secondary principal stresses for the face are shown on Figures 29 and 30 with a maximum tensile stress of 5500 psi occurring at contour 11 in Figure 29.

The primary and secondary principal stress directions are shown for the back of the blade in Figures 31 and 32. They are shown for the face of the blade in Figures 33 and 34. As illustrated, the maximum stress vectors are oriented generally in the radial direction.

The stresses are also presented in the form of chordwise distribution of principal stresses at specified radii as shown in Figures 35 to 42. These values, together with the stress directions, are useful in locating strain gauges for experimental stress measurements.

7.2 Propeller NSMB 5363

The primary and secondary principal stress contours for the back of the NSMB 5363 blade are shown on the transverse view in Figures 43 and 44. The maximum tensile stress for this surface is 4500 psi, which occurs at contour 18 (Figure 43) at the trailing edge near the start of the fillet. The maximum compressive stress on the back of -5000 psi occurs at contour 1 away from the trailing edge towards mid chord. These results can be compared with the stresses reported by NSMB[7] and reproduced in Figure 45 in English units. There is very good agreement in the stress contour pattern with NSMB reporting -4900 psi as the maximum compressive stress.

The principal stress contours for the face of the blade are shown in Figures 46 and 47. The maximum tensile stress of 7000 psi occurring at contour 14 in the region of the filet away from the trailing edge towards the mid chord. The face stresses reported by NSMB[7] have a maximum value of 6100 psi as shown in Figure 48. Here again the stress contour patterns obtained using PVAST are shown to be in good agreement with NSMB results, though the maximum stress is 900 psi higher. This may be due to the fact that the stresses predicted by PVAST go to the extreme boundaries while the NSMB results appear not to go beyond mid point in the boundary elements.

The stresses on the face due to centrifugal loads at 143 rpm are shown in Figure 49 for the DREA analysis and in Figures 50 for NSMB results. The stresses on the back are show in Figures 51 and 52. The stress contour patterns are nearly identical although the PVAST results shown a maximum stress which is 178 psi lower than predicted by NSMB for the face and 249 psi higher for the back.

The principal stress directions for the combined loading case are given in Figures 53 and 54. The chordwise principal stress distribution for 0.200, 0.525, 0.745, and 0.915 fractions of the full blade radius are shown in Figures 55 to 62.

The stresses predicted by PVAST for the NSMB 5363 blade are not significantly higher than the original NRC 45 blade. The maximum stress, however, is 7000 psi in tension instead of compression, which may make the blade more susceptible to fatigue should dynamic stress components be added to the steady stress values in the presence of an undetected stress concentration. The higher tensile stress for NSMB 5363 is due to skew, which magnifies the effect of centrifugal forces moving it towards the trailing edge near the start of the blade fillet.

8. BLADE SECTION DISTORTION

Blade section distortion is shown graphically in Figures 63 to 66 for the NRC 45 blade. Outlines of the fully developed sections are displayed at 0.320, 0.520, 0.710 and 0.920 fractions of the full radius of the propeller. The displacements have been scaled up by a factor of 40 to emphasize the effect. The deflections can be scaled from the drawing by measuring the displacement shown as dimension D in Figure 63 and multiplying and dividing by the given scale factors.

$$\text{DEFLECTION} = \frac{\text{DIMENSION SCALE} \times \text{D}}{1.7 \times \text{SCALE FACTOR}}$$

The distortion of the blade section for the NSMB 5363 propeller is shown graphically in Figures 67 to 70. The loaded outline is shown at its deflected position relative to the unloaded outline at 0.325, 0.525, 0.745 and 0.915 radius. The mid chord deflection of 0.106 inches at the 0.92 nominal radius is somewhat less than that for the NRC 45 blade (Figure 66). Twisting of the blade section, however, is apparent, which is not present in the NRC 45 blade. When converted to the true dimensions, the angle of twist is only 0.175 degrees, which is not significant.

9. NATURAL FREQUENCIES

The natural frequencies of vibrations of the propeller blades in water are given together with the contour plots of the mode shapes in Figures 71 to 84. The frequencies are also presented in Table 1. Both the frequencies in air and the frequencies in water are given.

The normalized displacement contour plot diagrams are used to display the mode shapes on the transverse projection of the face of the blade. Only the vibratory modes in water have been presented in this form which show motion toward the observer as solid lines and motion away from the observer as short dashed lines. The large dashed lines show zero motion and represent the nodal lines of the vibration.

There is a difference in the natural frequencies of the NRC 45 blade compared to the NSMB 5363 as can be seen in Table 1. The fundamental frequencies in water are 36.6 Hz for the NRC 45 blade and 22.9 Hz for the NSMB blade. The rotational speed for the NSMB 5363 propeller is about 2.4 rps. This is equivalent to a shaft rate of 2.4 Hz and a blade rate of 11.9 Hz. Harmonics of these frequencies are close to the fundamental frequency of the NSMB blade.

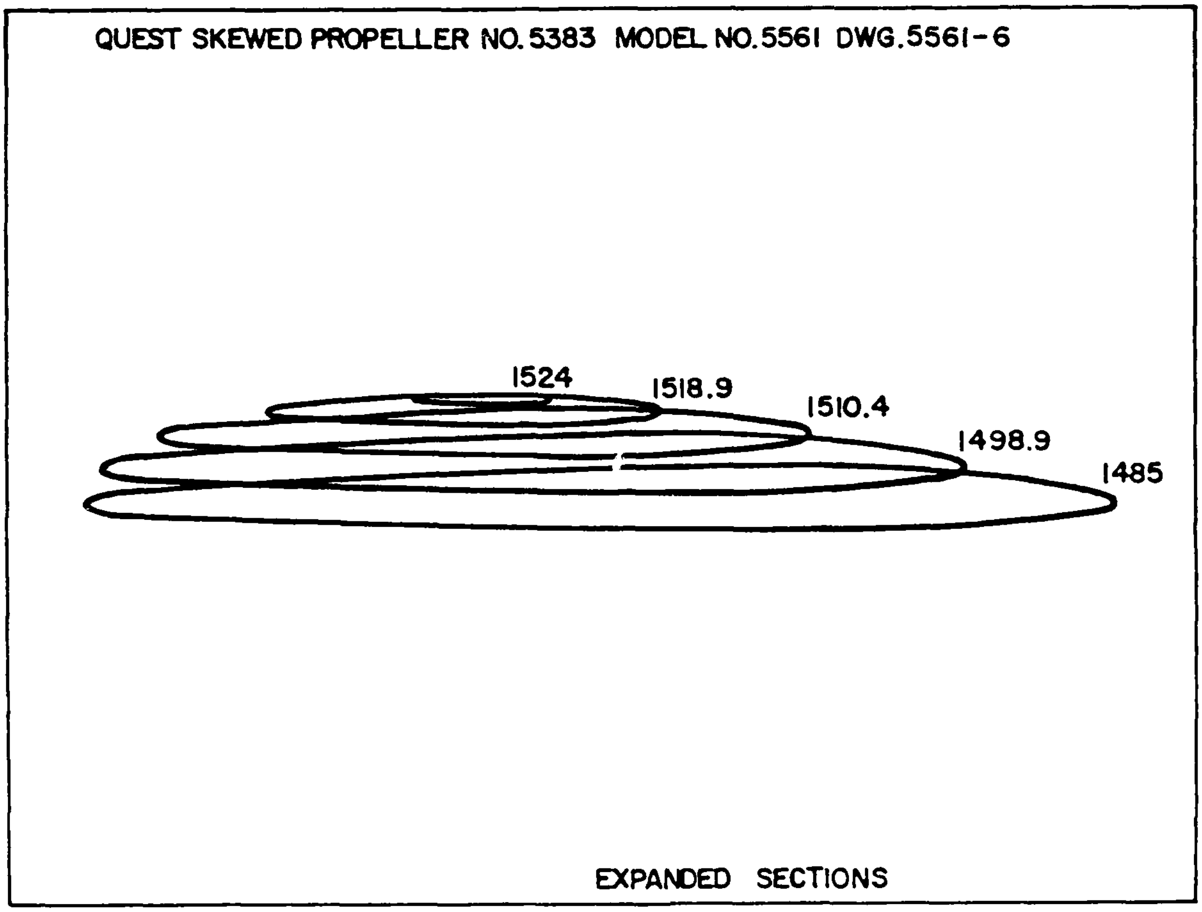


FIG. 12 EXPANDED SECTIONS GENERATED FOR THE TIP OF THE NSMB 5363 PROPELLER BLADE

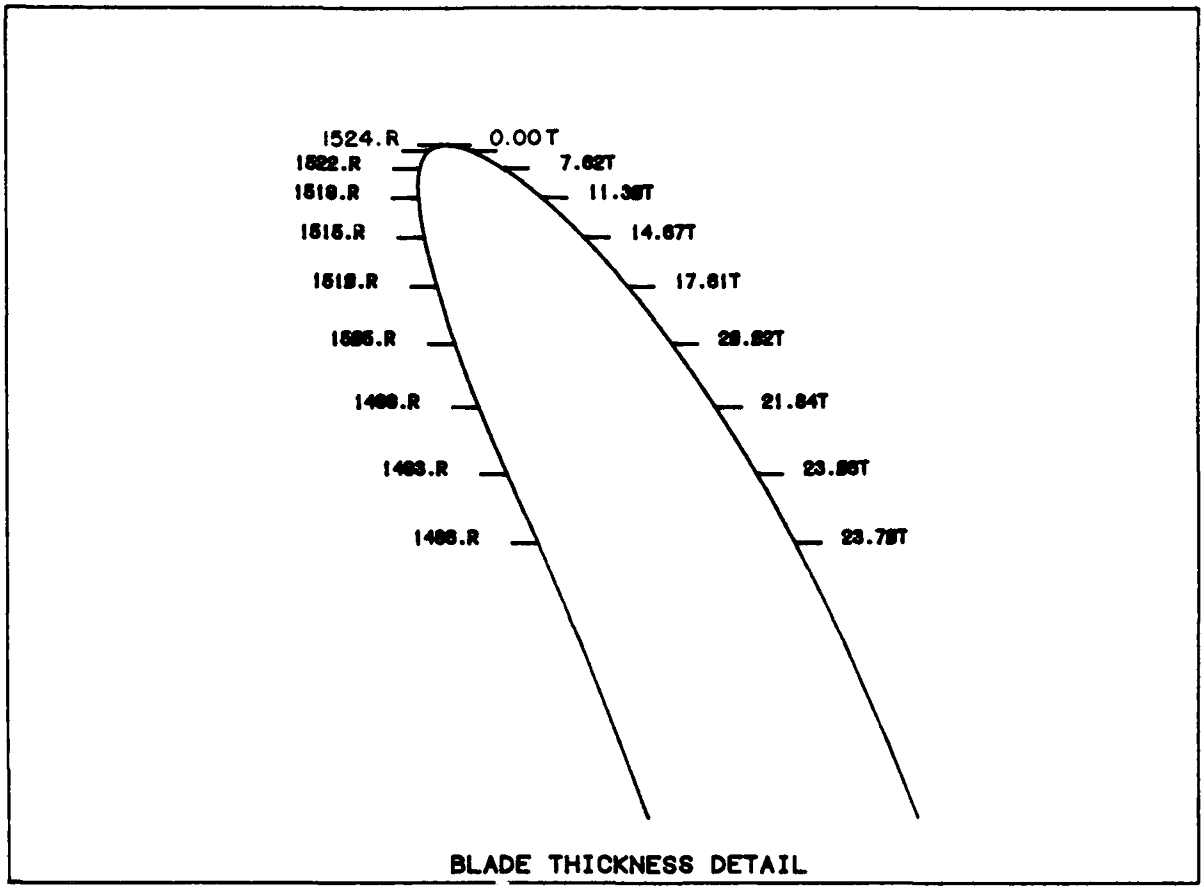


FIG. 11 ENLARGED VIEW OF BLADE THICKNESS AT TIP OF NSMB 5363 PROPELLER BLADE

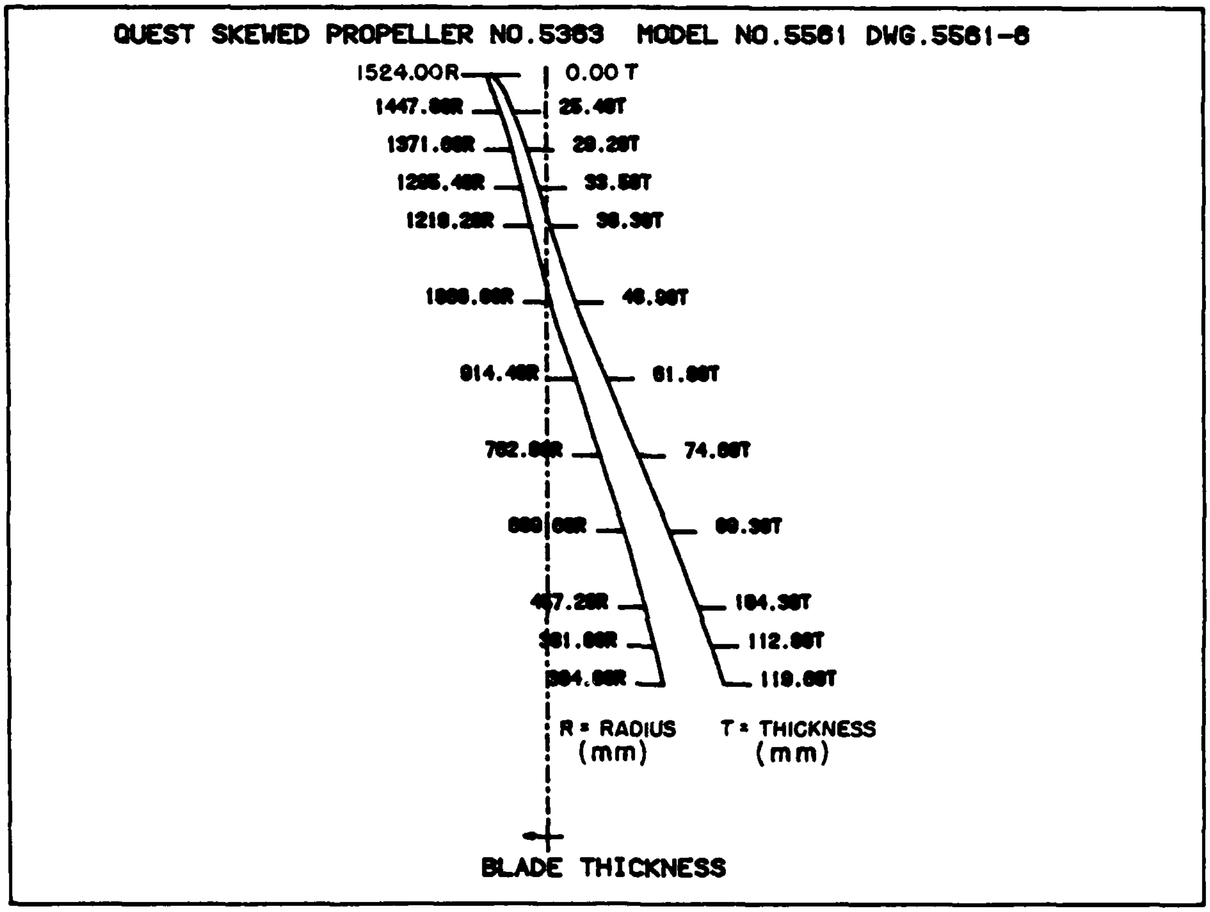


FIG. 10: MAXIMUM THICKNESS DIAGRAM FOR THE NSMB 5363 PROPELLER BLADE

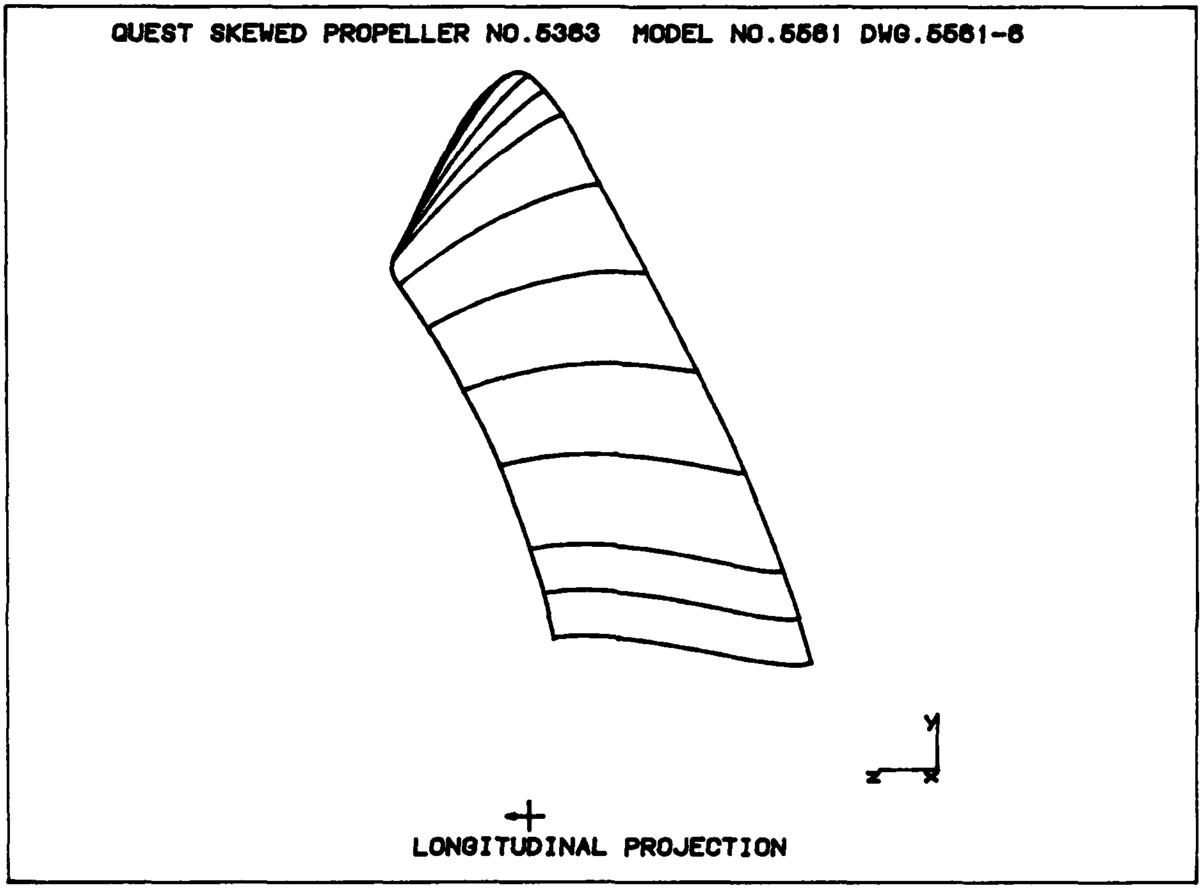


FIG. 9 LONGITUDINAL VIEW OF THE NSMB 5363 PROPELLER

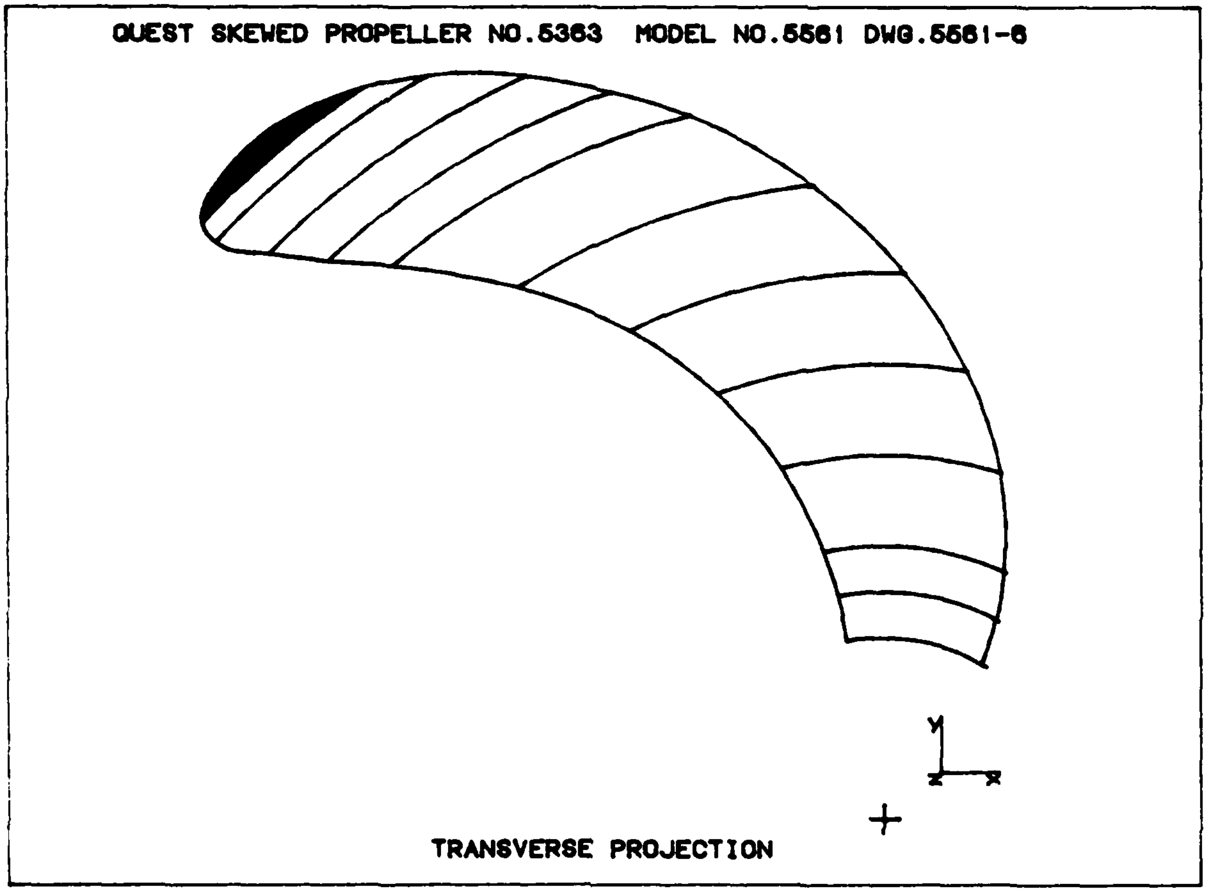


FIG. 8 TRANSVERSE VIEW (PROJECTED OUTLINE) OF THE NSMB 5363 PROPELLER BLADE

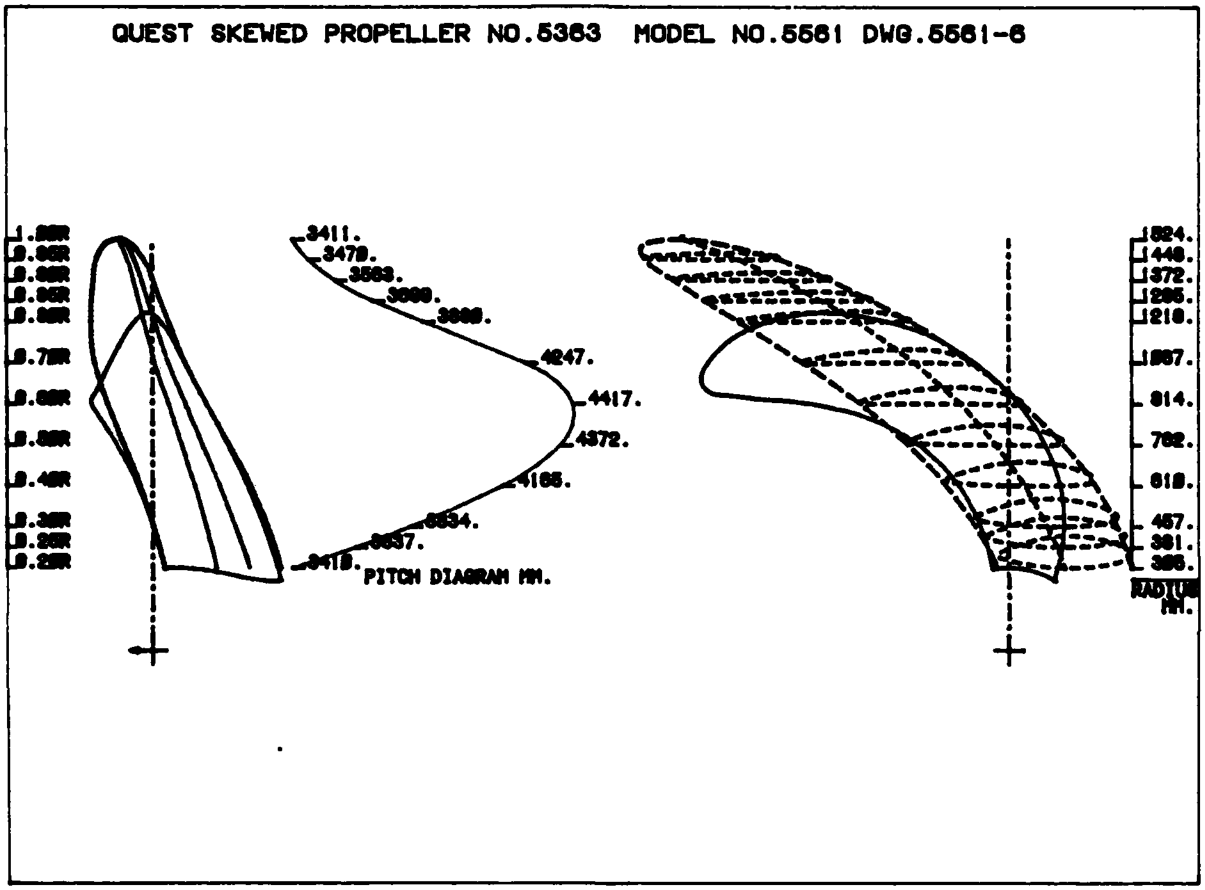


FIG. 7 PROPELLER BLADE GEOMETRY FOR THE NSMB 5363 PROPELLER BLADE

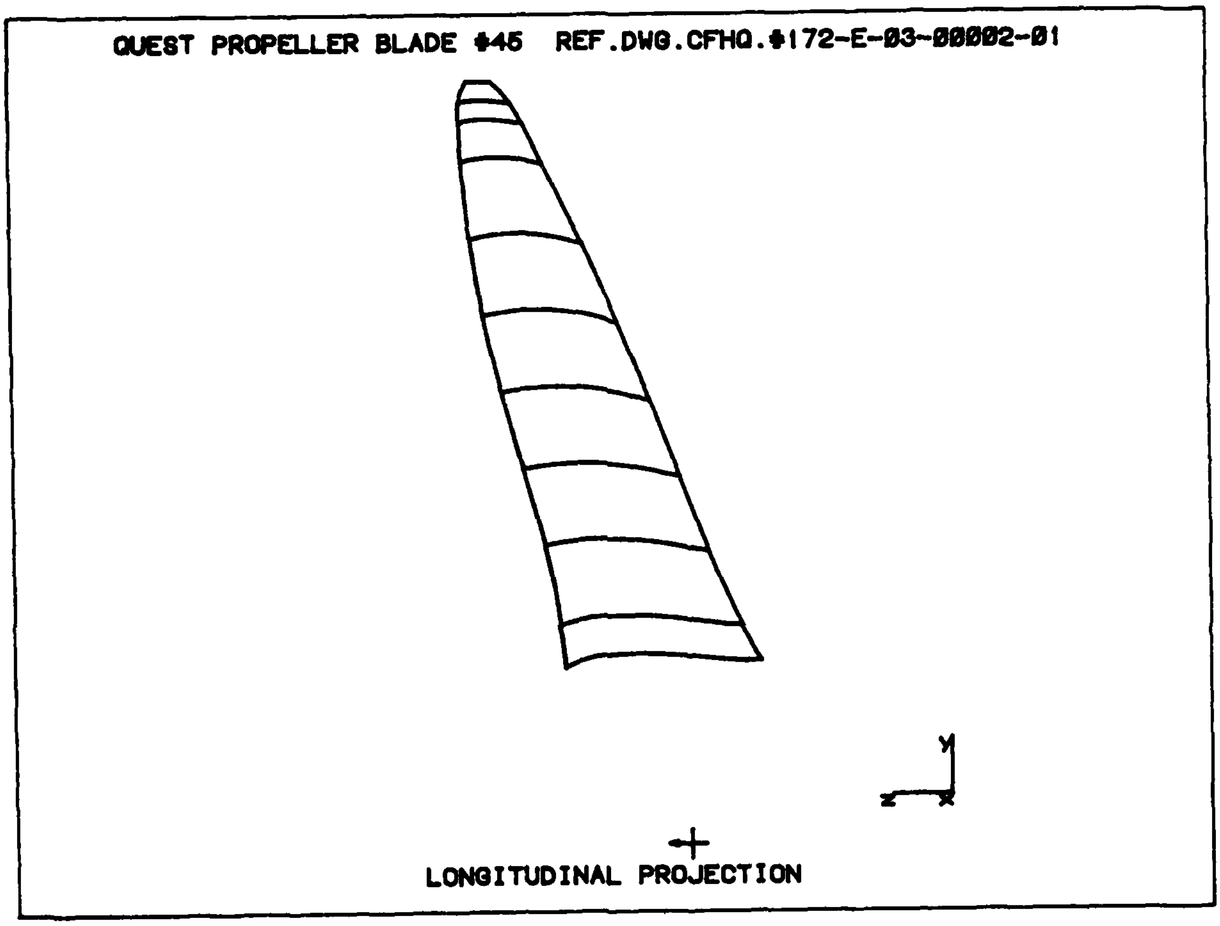


FIG. 6 LONGITUDINAL VIEW OF THE NRC 45 PROPELLER BLADE

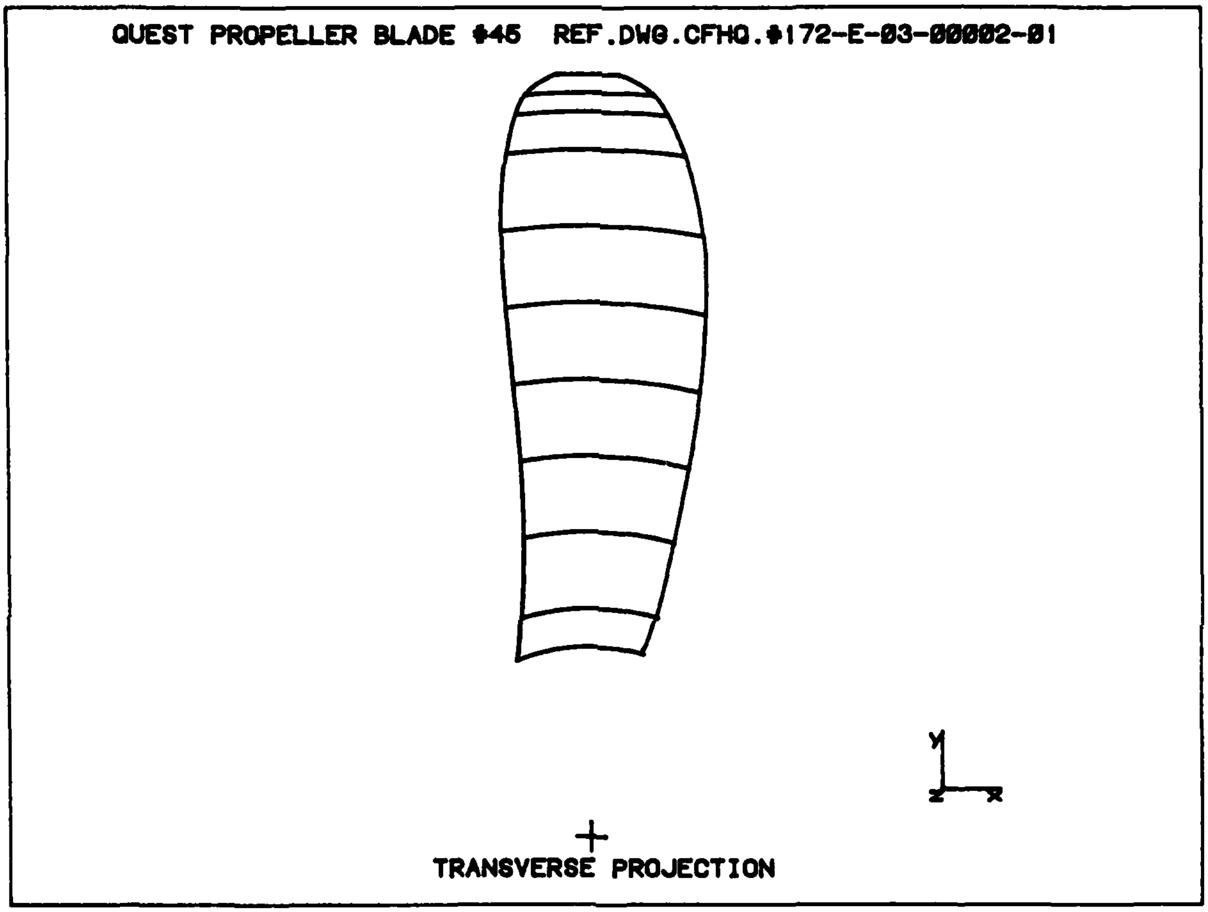


FIG. 5 TRANSVERSE VIEW (PROJECTED OUTLINE) OF THE NRC 45 PROPELLER BLADE

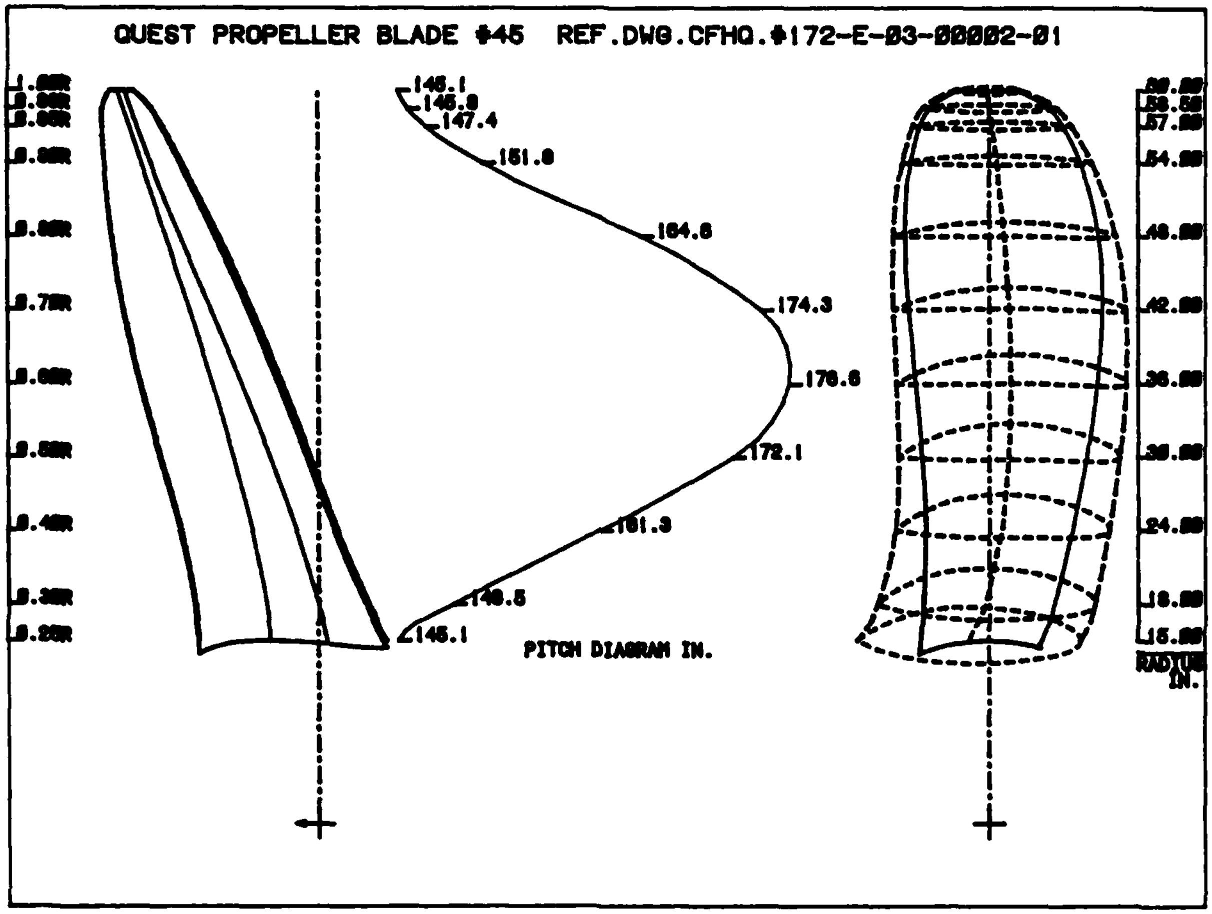


FIG. 4 PROPELLER BLADE GEOMETRY FOR THE NRC 45 PROPELLER BLADE

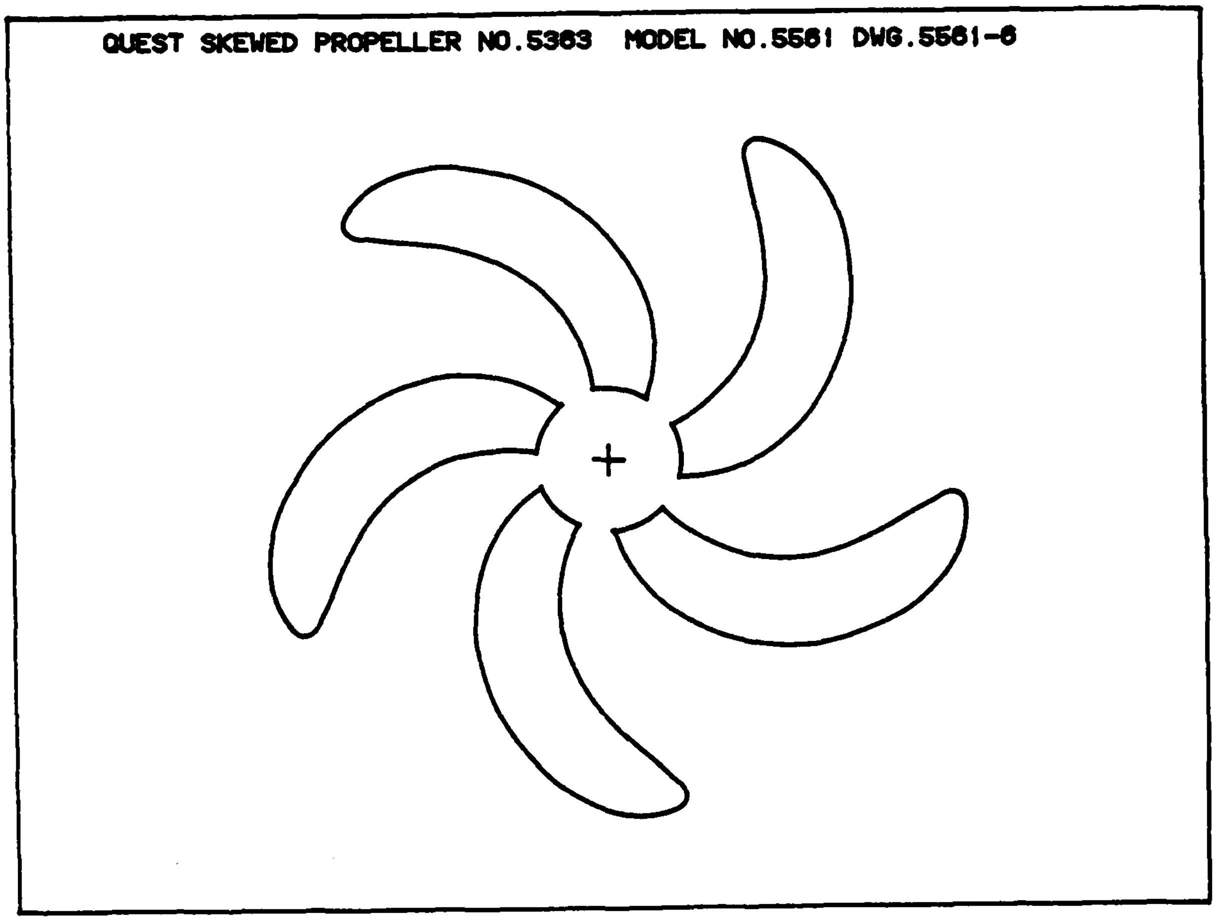


FIG. 3 TRANSVERSE VIEW OF THE NSMB 5363 PROPELLER

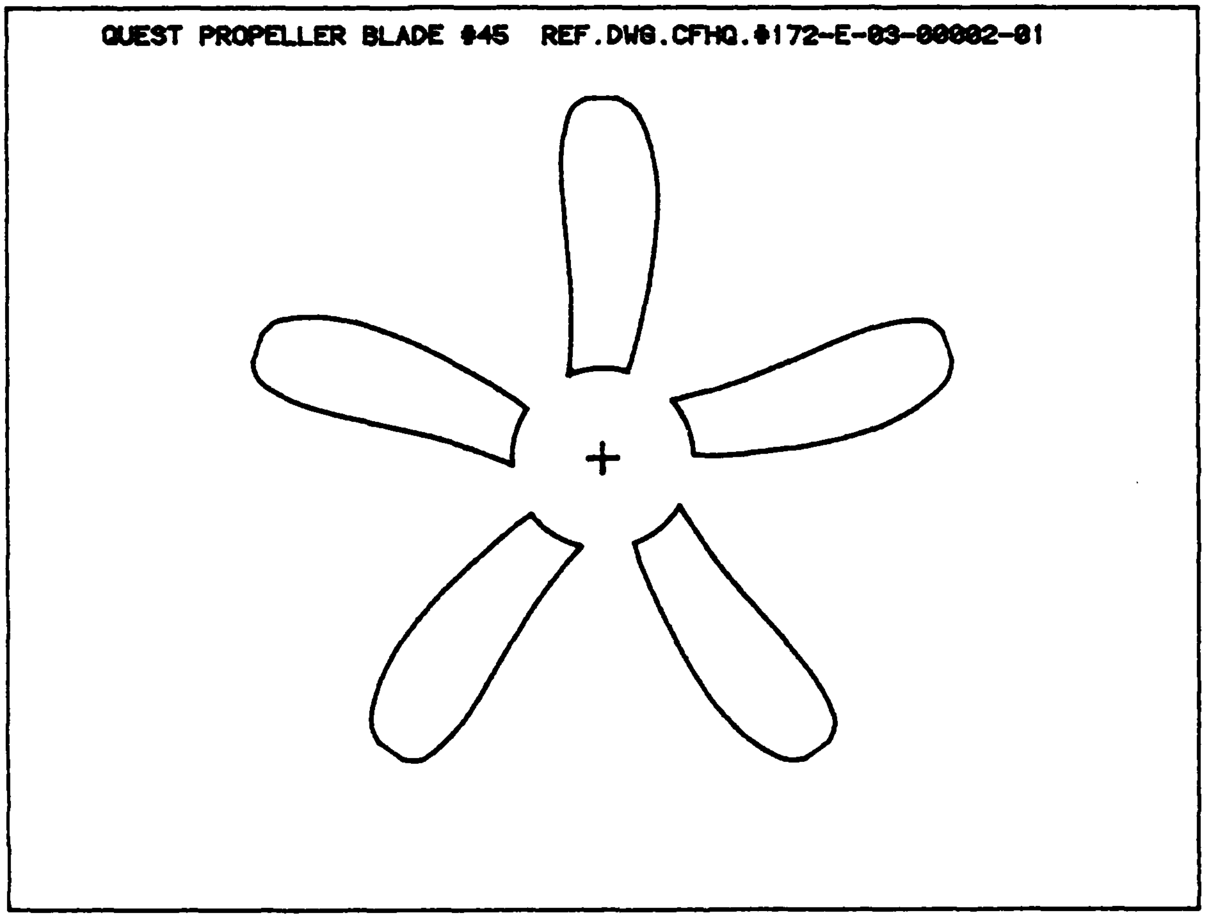


FIG. 2 TRANSVERSE VIEW OF THE NRC 45 PROPELLER

FIG. 1 CFAV QUEST WITH NRC 45 PROPELLERS INSTALLED

TABLE 1: NATURAL FREQUENCY OF VIBRATION NRC 45 AND NSMB 5363 PROPELLERS

	NRC 45			NSMB 5363		
MODE	AIR	WATER		AIR	WATER	
1	67.9	36.6	Ist Bending	40.1	22.9	Ist Bending
2	166.0	112.8	2nd Bending	94.3	67.4	2nd Bending
3	242.0	154.2	Ist Torsion	126.0	111.4	Ist Torsion
4	272.2	233.6	Bending	201.0	145.1	Torsion
5	373.0	286.6	Bending	268.0	196.0	Torsion
6	421.0	292.9	Torsion	346.0	269.0	Torsion
7	620.0	469.9	Bending	435.0	331.0	Torsion

10. CONCLUSIONS

The original propeller NRC 45, designed for CFAV QUEST, has been analyzed for strength and vibration, together with the new propeller, NSMB 5363. There is a good agreement between the stress results obtained using the finite element program PVAST and those reported by NSMB using the finite element program NASTRAN. The maximum compressive stress on the back of the blade under combined pressure and centrifugal loading was determined to be -5000 psi compared to -4900 psi reported by NSMB.

On the face of the blade there was good match between the stress contour patterns, with a maximum tensile stress of 7000 psi obtained using PVAST compared to 6100 psi for the NSMB results. The difference of 900 psi is due possibly to the stresses being calculated by PVAST to the extreme boundaries of the propeller blade, while the NSMB results appear not to go beyond the mid point of the boundary elements.

The PVAST analysis further showed that the stresses predicted for the NSMB 5363 blade are not significantly higher than those predicted for the NRC 45 blade. The maximum stress is 7000 psi in tension and -5000 psi in compression compared to 5500 psi in tension and -7000 psi in compression for the NRC 45 blade. This higher tensile stress may make the NSMB 5363 more susceptible to fatigue failure should dynamic stress components add to the steady stress values in the presence of undetected stress concentrations.

With reference to blade section distortion, the NSMB blade was shown to be stiffer under combined pressure and centrifugal loading. A deflection of 0.106 inches at the *.92 fraction of* the full radius was predicted compared to 0.176 inches for the NRC blade. The NSMB blade, however, was shown to have less torsional rigidity with a twist of 0.175 degrees compared with an essentially zero twist for the NRC 45 blade at the same radius.

The natural frequency analysis, as summarized in Table 1, shows the NSMB 5363 blade to have lower natural frequencies of vibration in water. The fundamental frequency of vibration predicted for the NSMB 5363 blade was 22.9 Hz versus 36.6 Hz for the NRC 45. The shaft rate and blade rate for the NSMB blade are 2.4 Hz and 11.9 Hz respectively at 143 RPM. Harmonics of these frequencies are close to the blade fundamental frequency of 22.9 Hz.

The two propellers have thus been shown to be approximately equal in strength and stiffness. There is a noticeable difference, however, in the natural frequencies of vibration in water between the two blades.

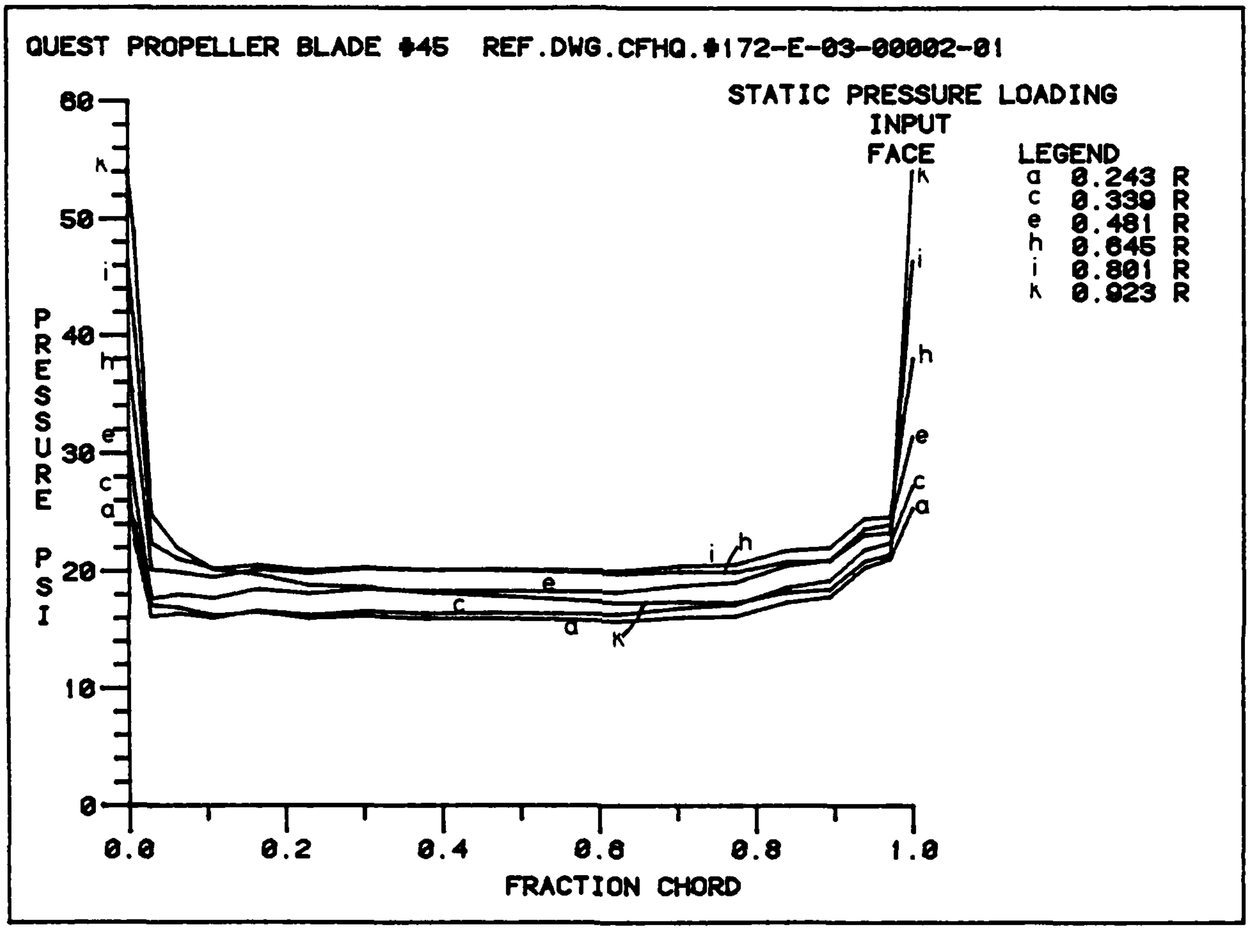


FIG. 13 BLADE FACE CHORDWISE LOADING FOR NRC 45 PROPELLER BLADE

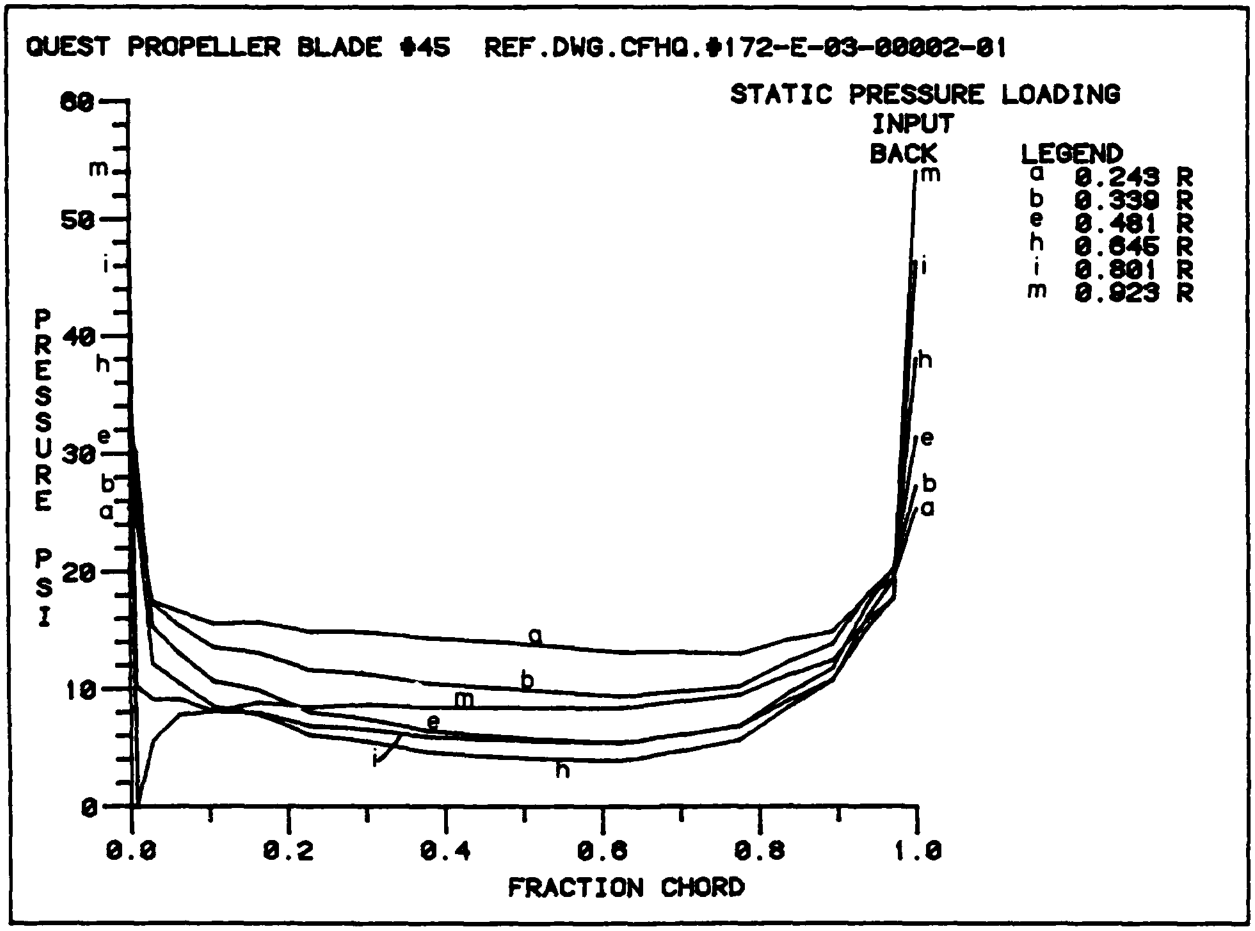


FIG. 14 BLADE BACK CHORDWISE LOADING FOR NRC 45 PROPELLER BLADE

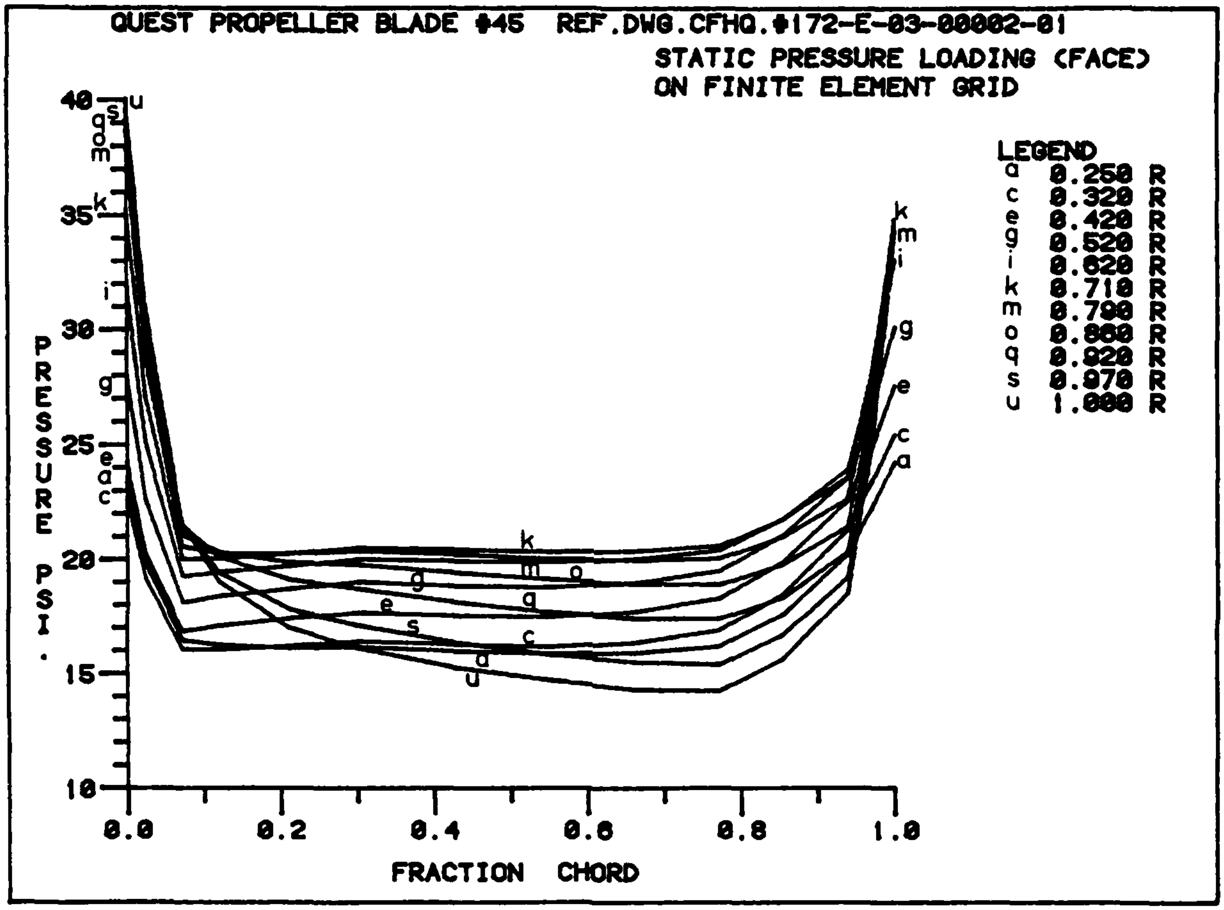


FIG. 15 FACE CHORDWISE LOADING INTERPOLATED BY PVAST FOR NRC 45 PROPELLER BLADE

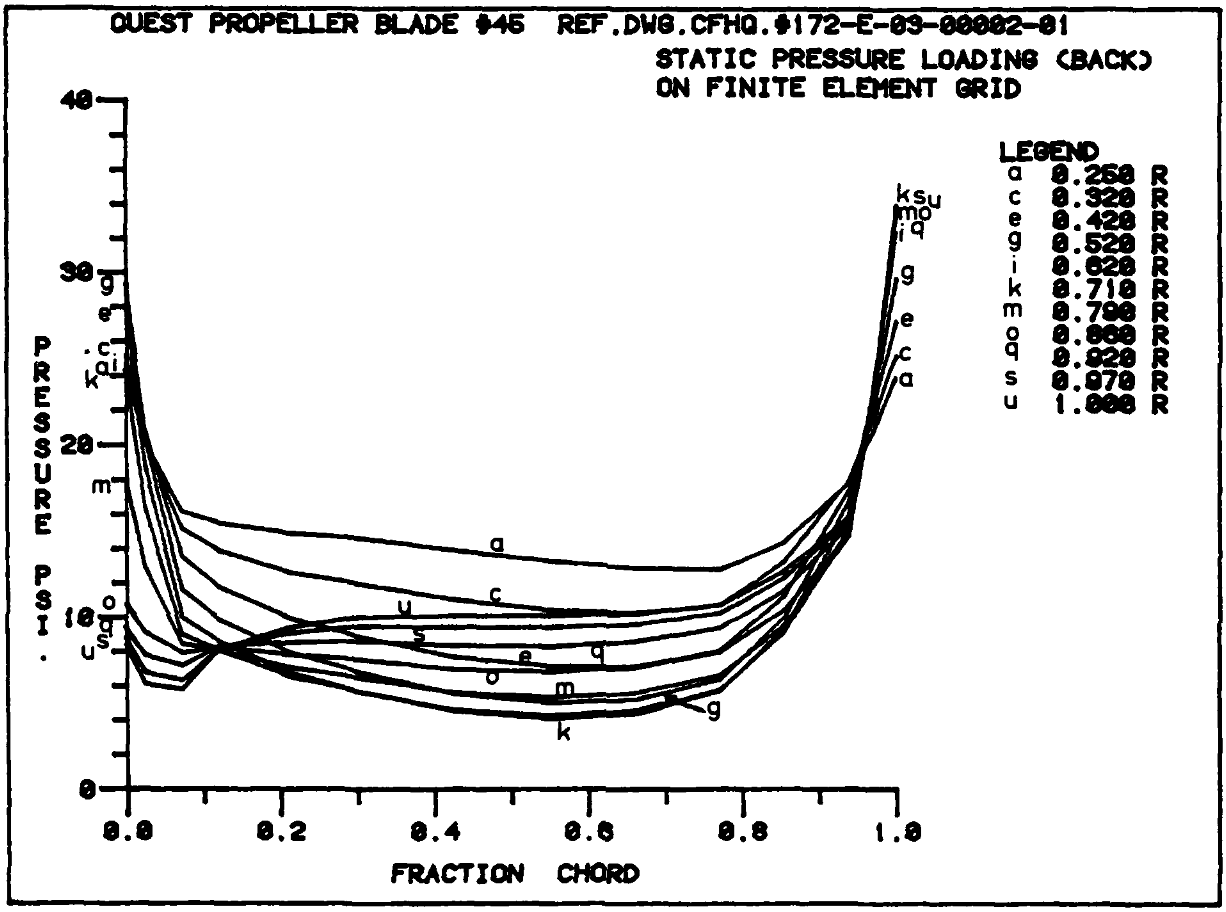


FIG. 16 BACK CHORDWISE LOADING INTERPOLATED BY PVAST FOR NRC 45 PROPELLER

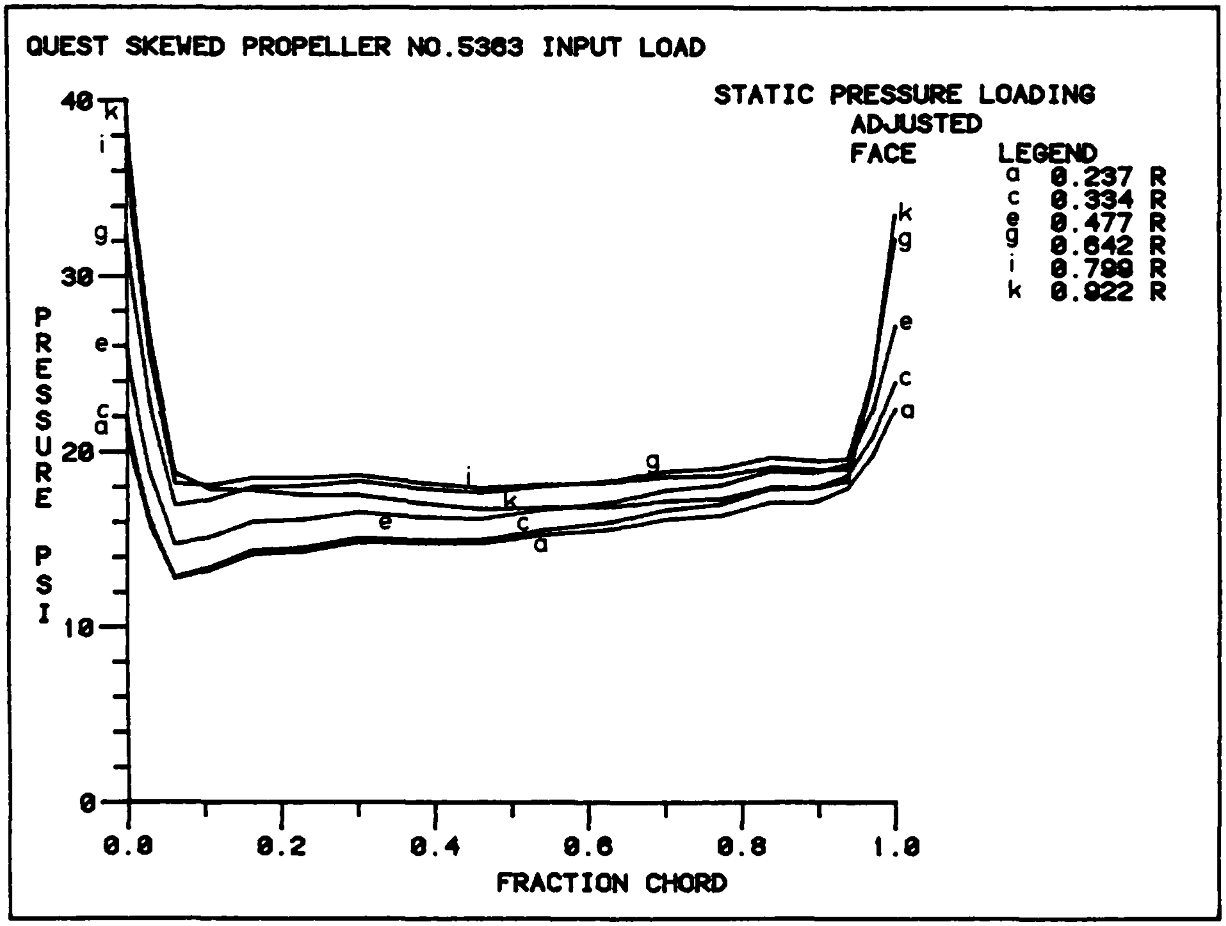


FIG. 17 BLADE FACE CHORDWISE LOADING FOR NSMB 5363 PROPELLER BLADE

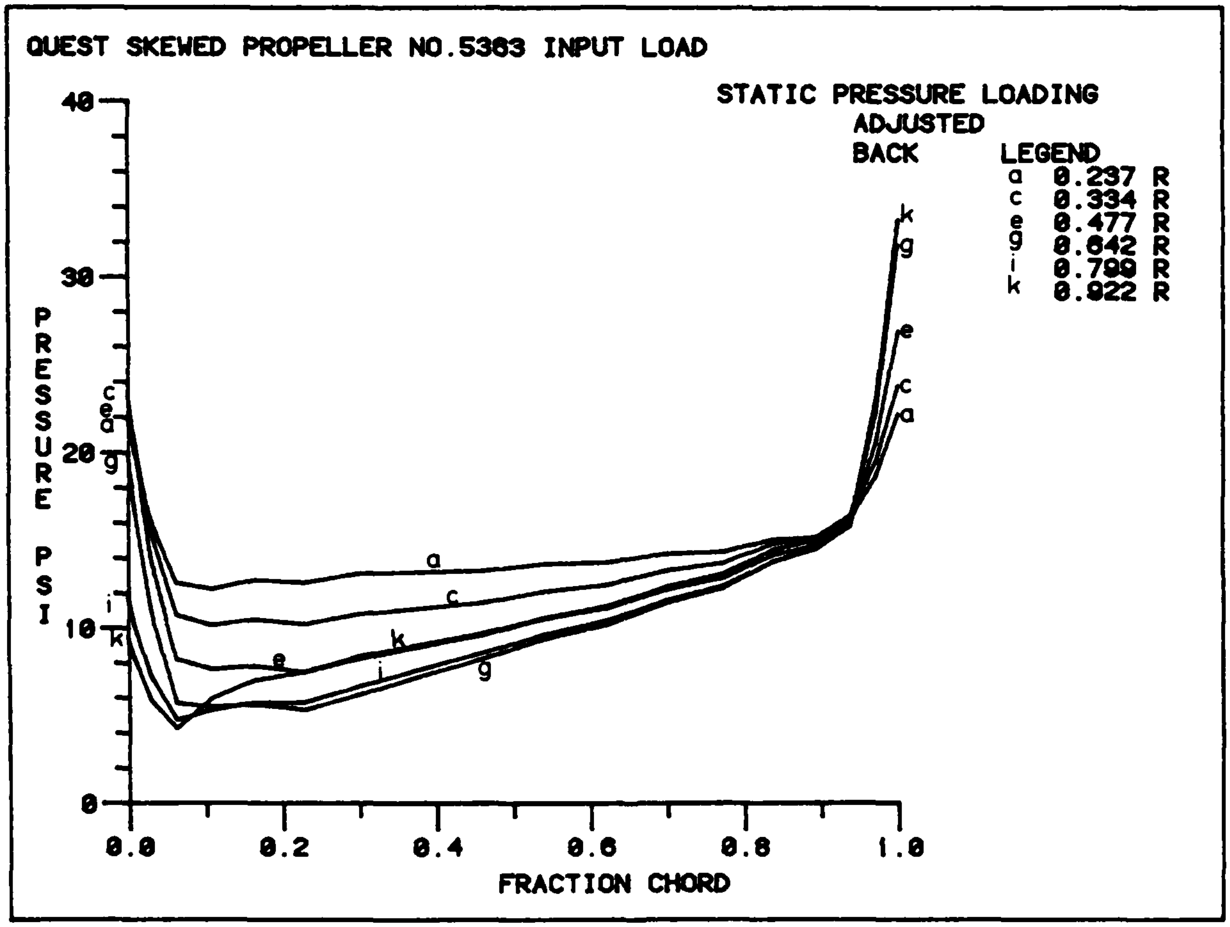


FIG. 18 BLADE BACK CHORDWISE PRESSURE LOADING FOR NSMB 5363 PROPELLER BLADE

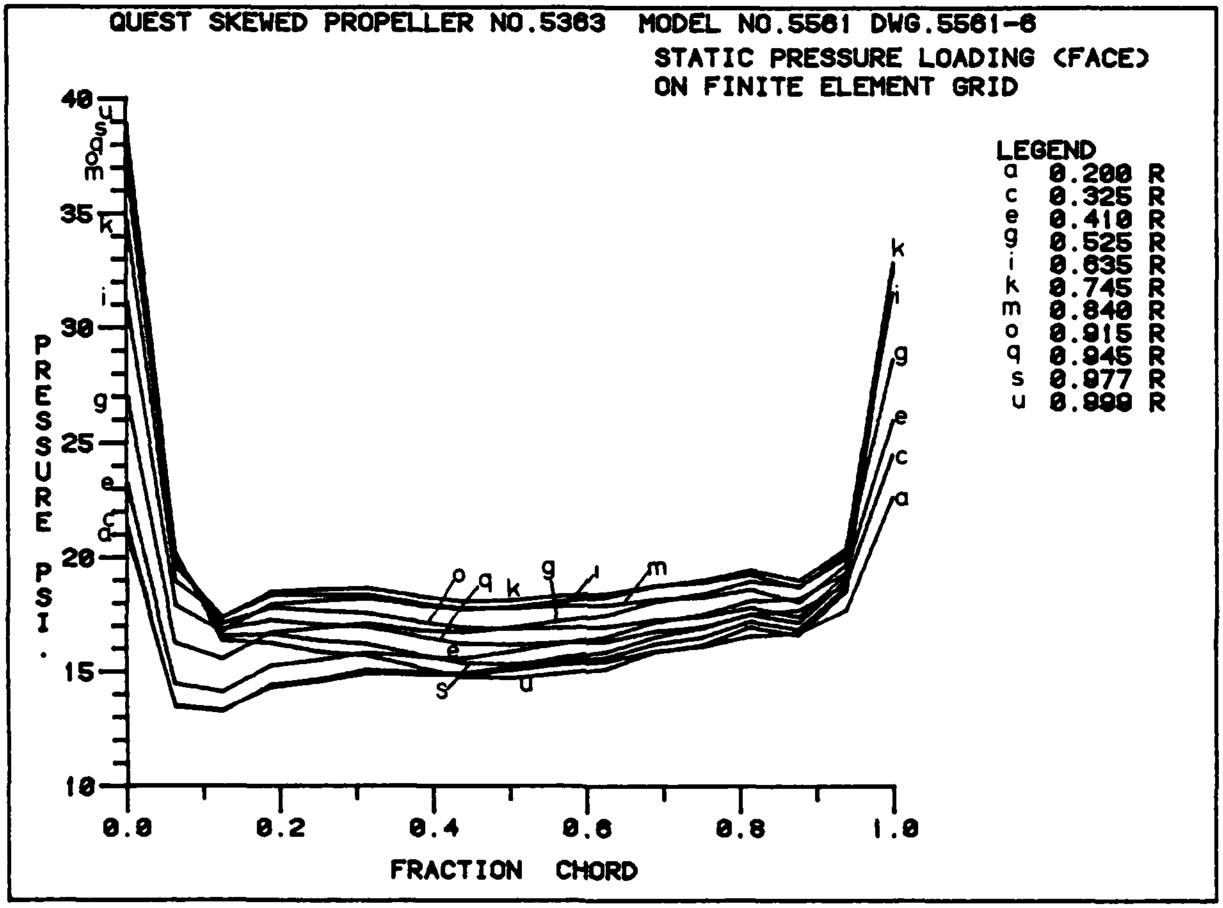


FIG. 19 FACE CHORDWISE LOADING INTERPOLATED BY PVAST FOR NSMB 5363 PROPELLER BLADE

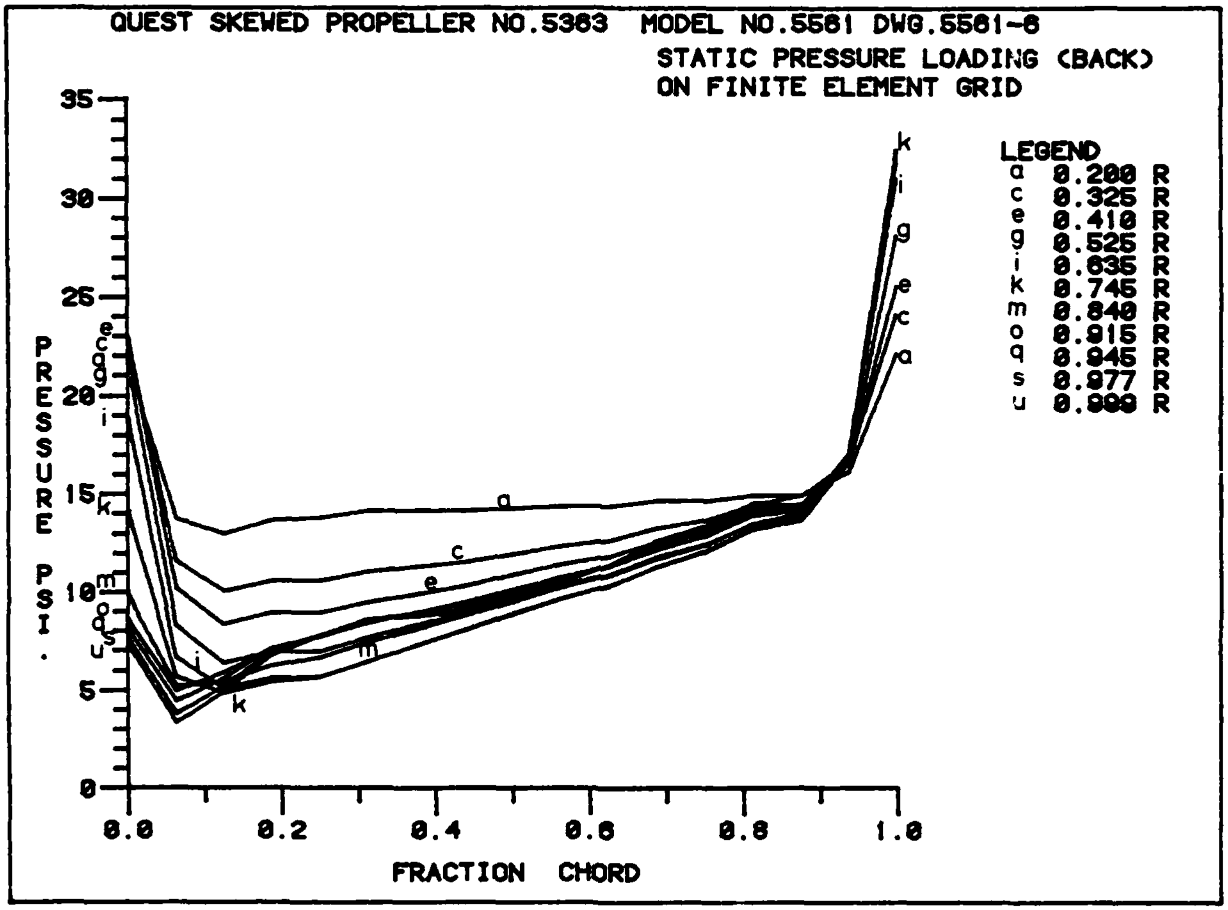


FIG. 20 BACK CHORDWISE LOADING INTERPOLATED BY PVAST FOR NSMB 5363 PROPELLER BLADE

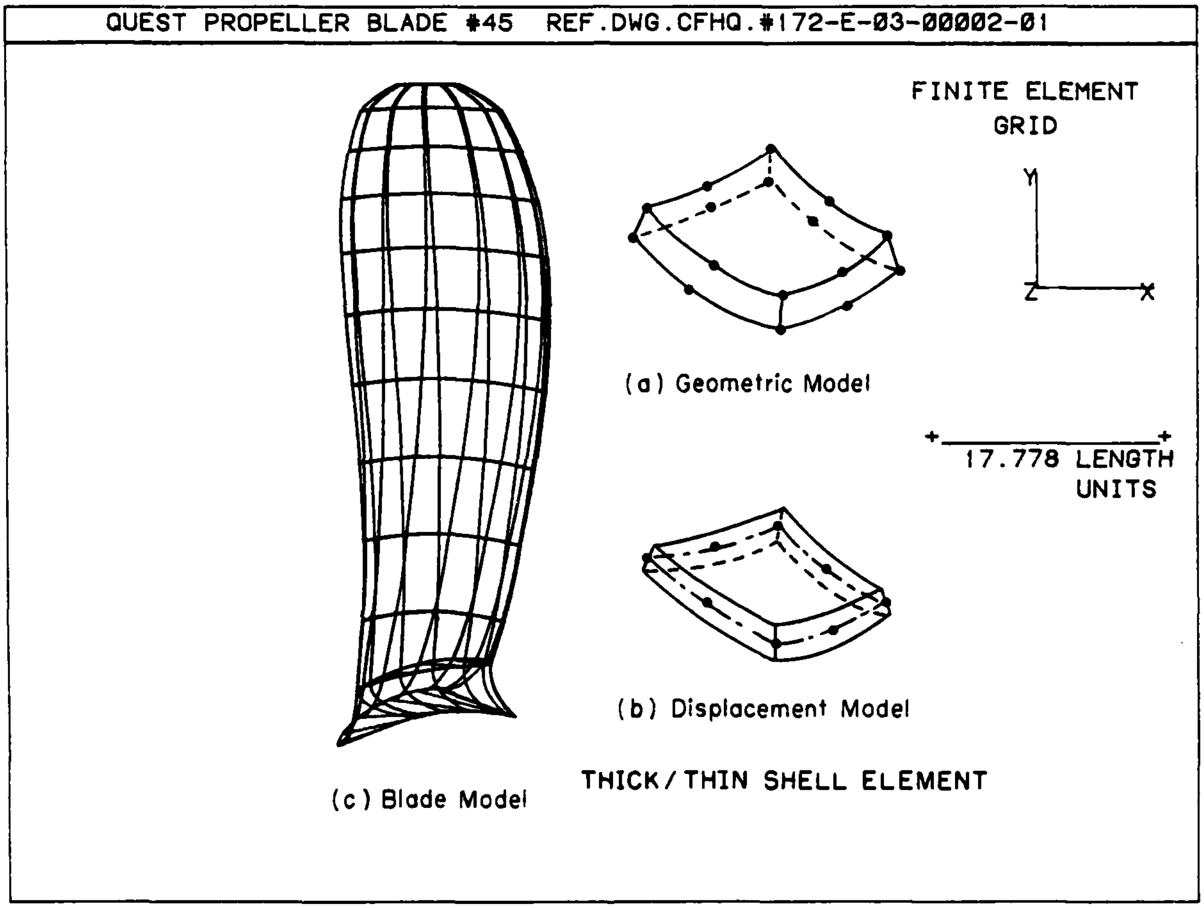


FIG. 21 FINITE ELEMENT MODEL FOR NRC 45 PROPELLER BLADE

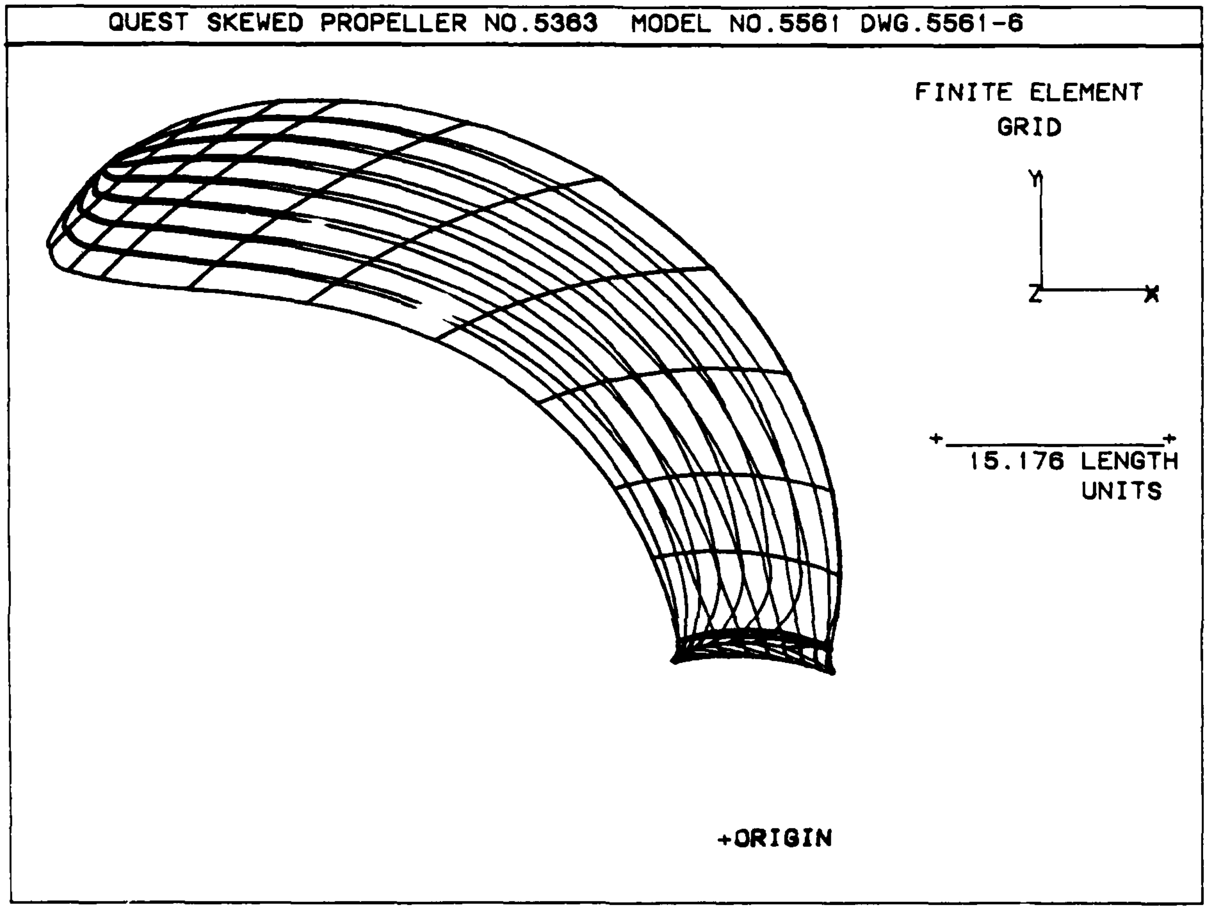


FIG. 22 FINITE ELEMENT MODEL FOR NSMB 5363 PROPELLER BLADE

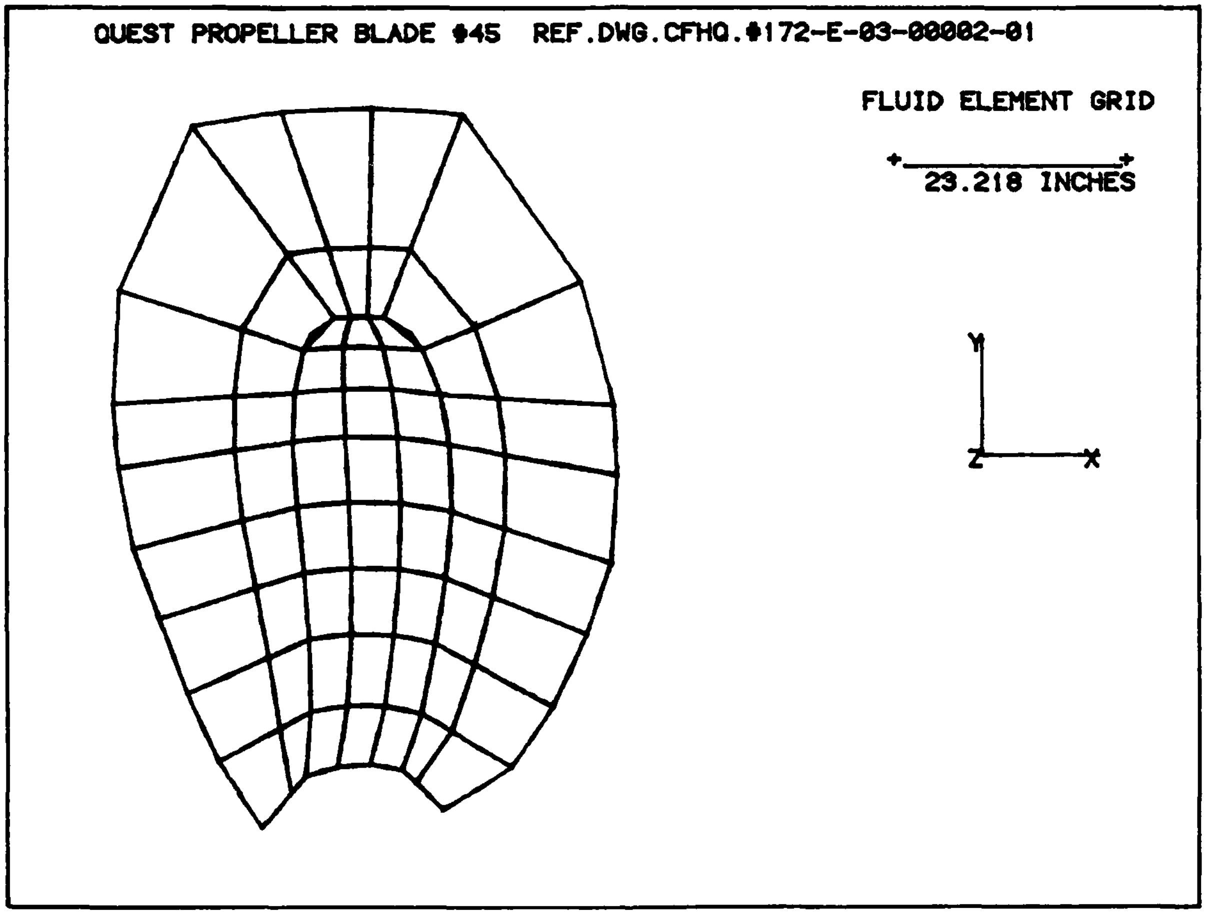


FIG. 23 2D PROJECTION OF FLUID ELEMENT MODEL FOR NRC 45 PROPELLER

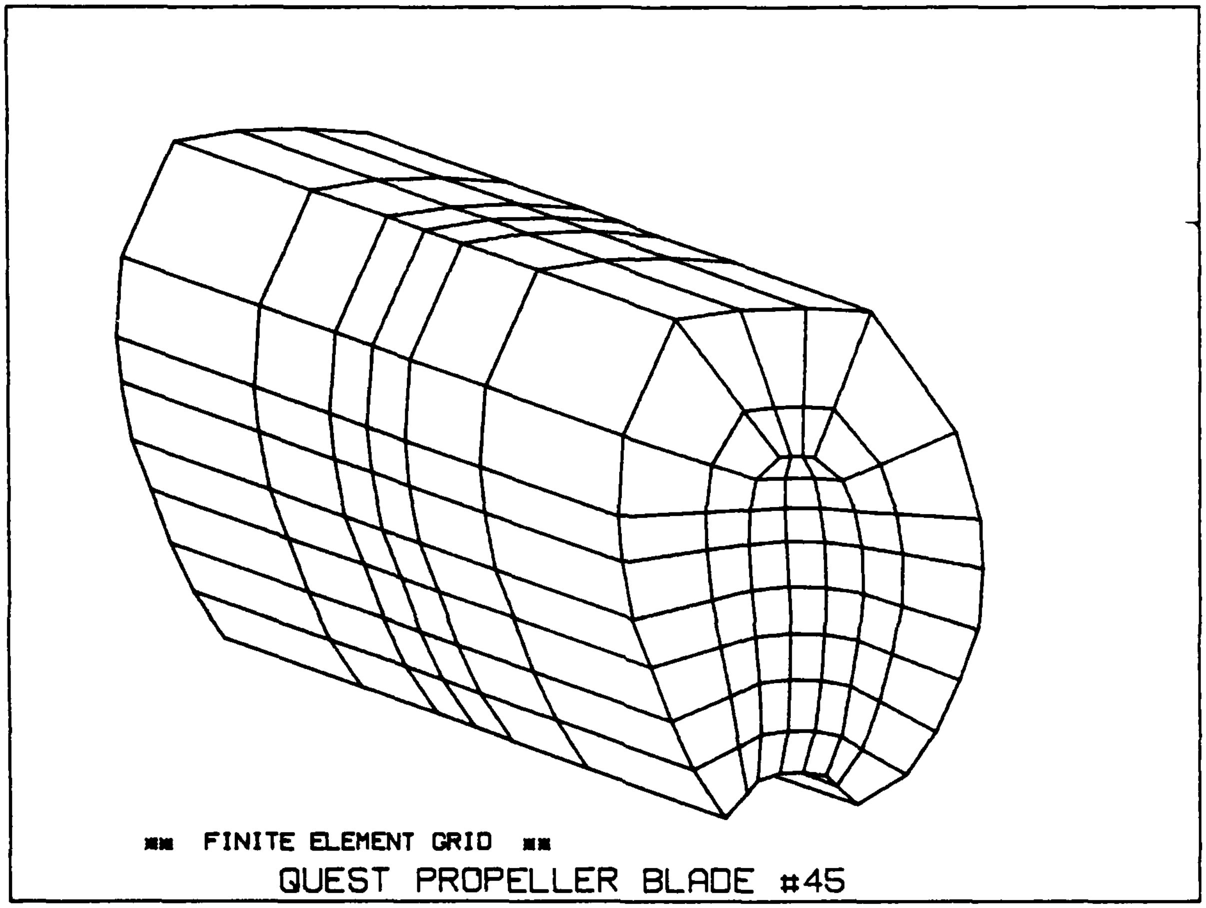


FIG. 24 3 DIMENSIONAL VIEW OF FLUID ELEMENT MODEL FOR NRC 45 PROPELLER BLADE

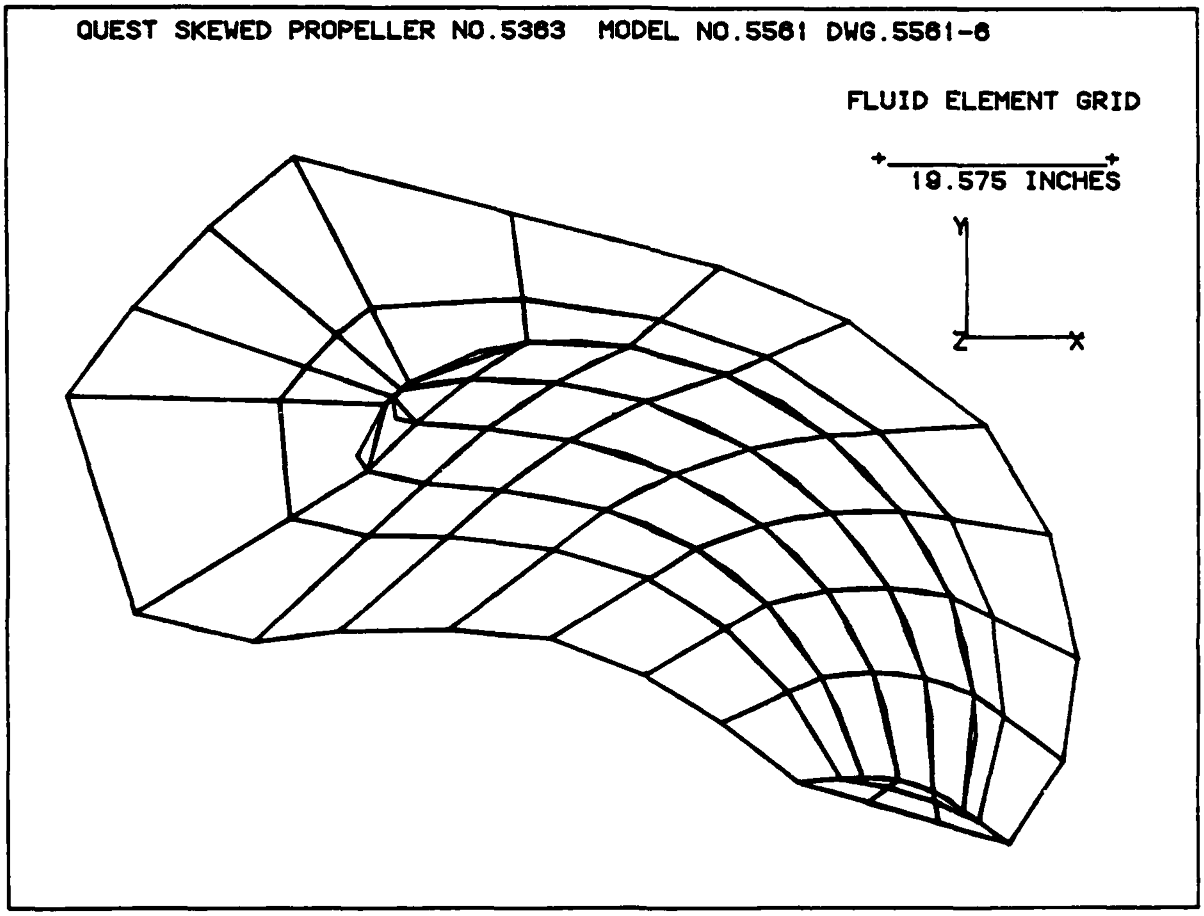


FIG. 25 2D VIEW OF FLUID ELEMENT MODEL FOR NSMB 5363 PROPELLER BLADE

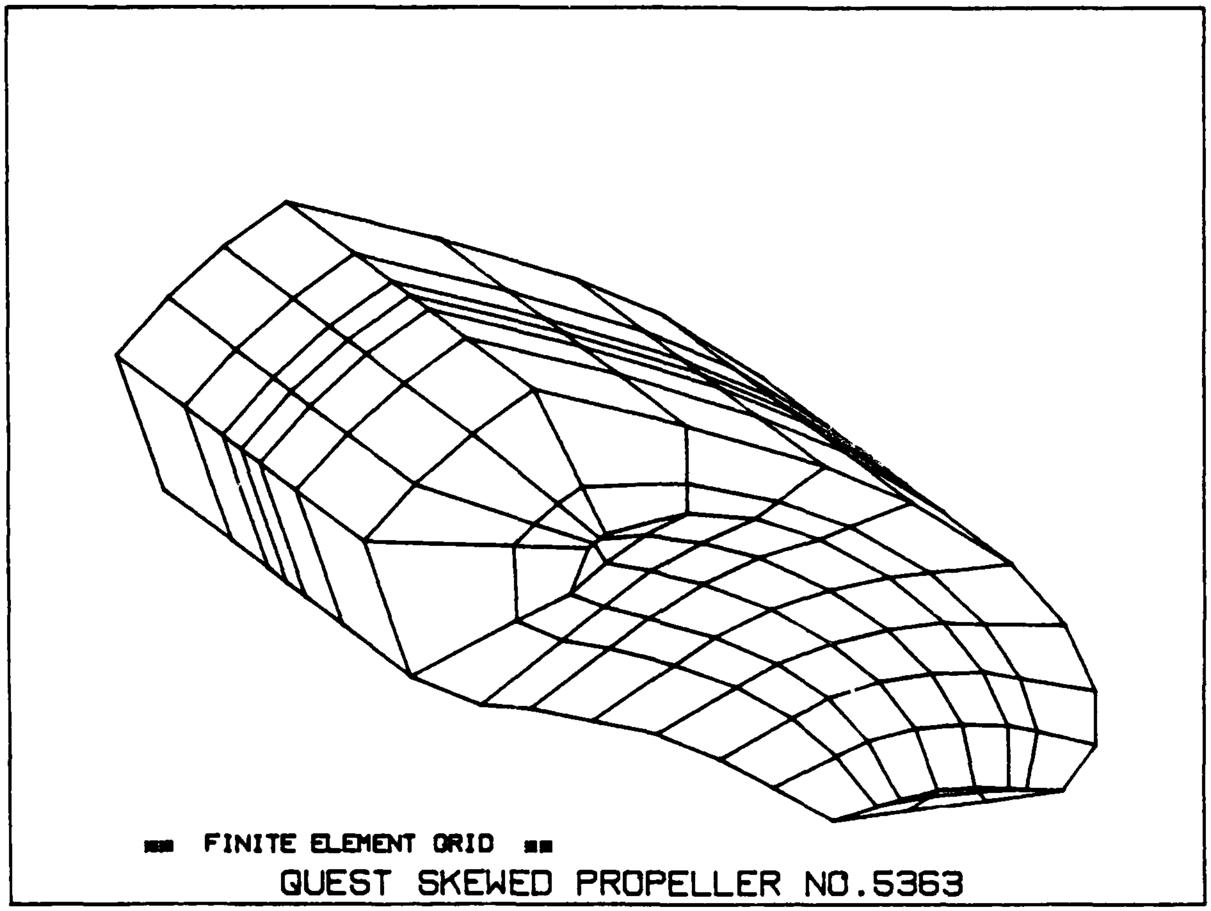


FIG. 26 3 DIMENSIONAL VIEW OF FLUID ELEMENT MODEL FOR NSMB 5363 PROPELLER BLADE

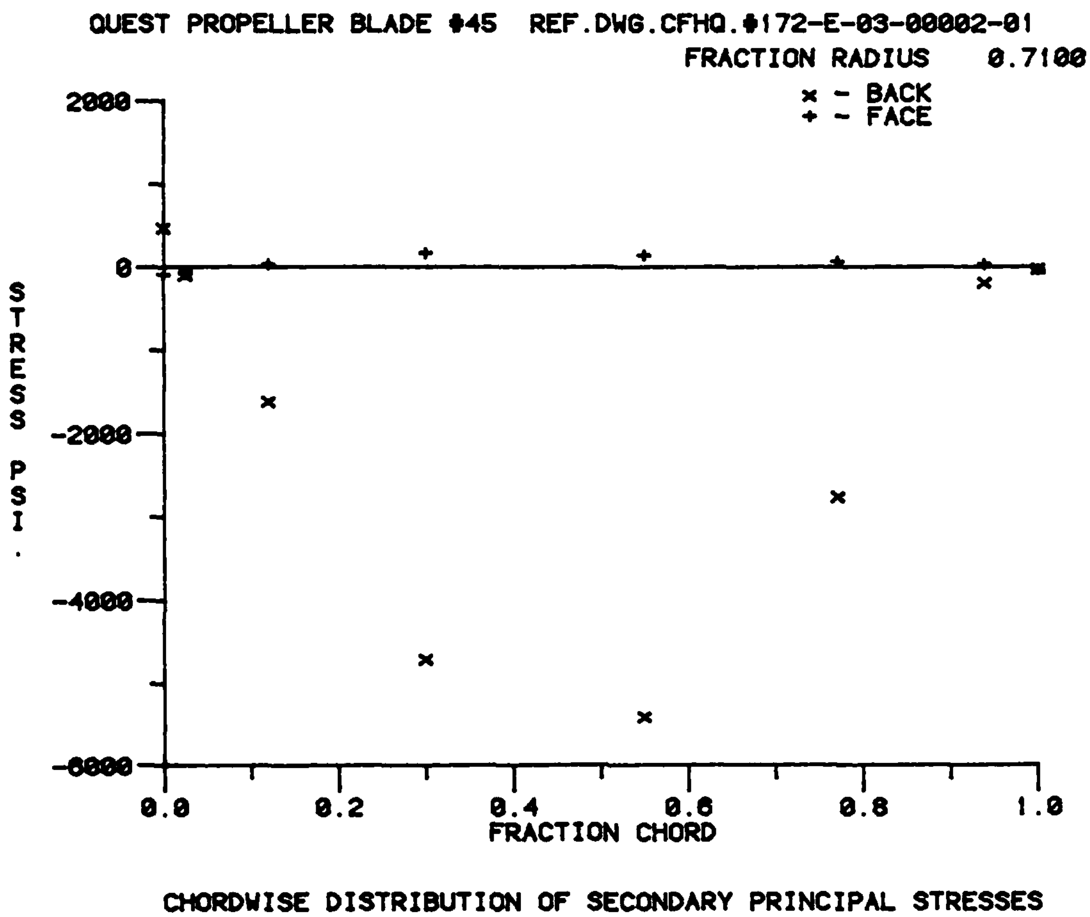


FIG. 40 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.71 FRACTION OF FULL RADIUS

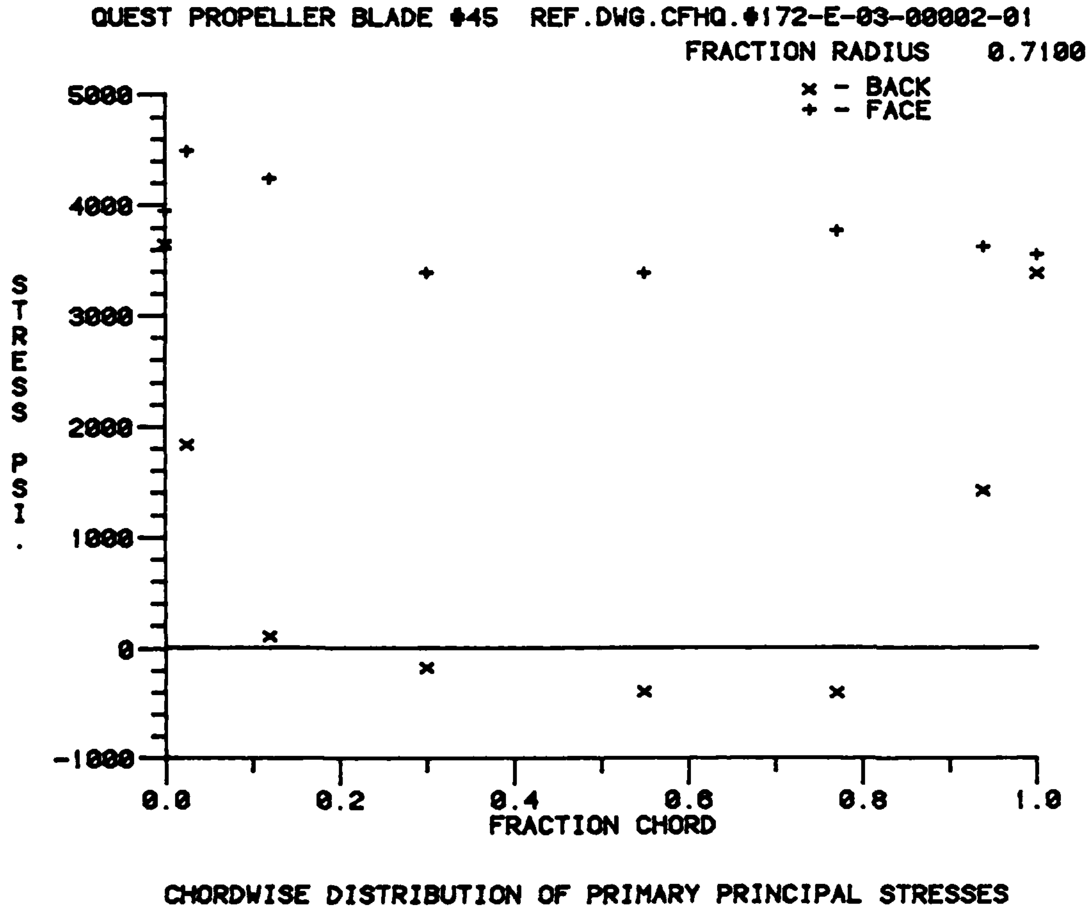


FIG. 39 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.71 FRACTION OF FULL RADIUS

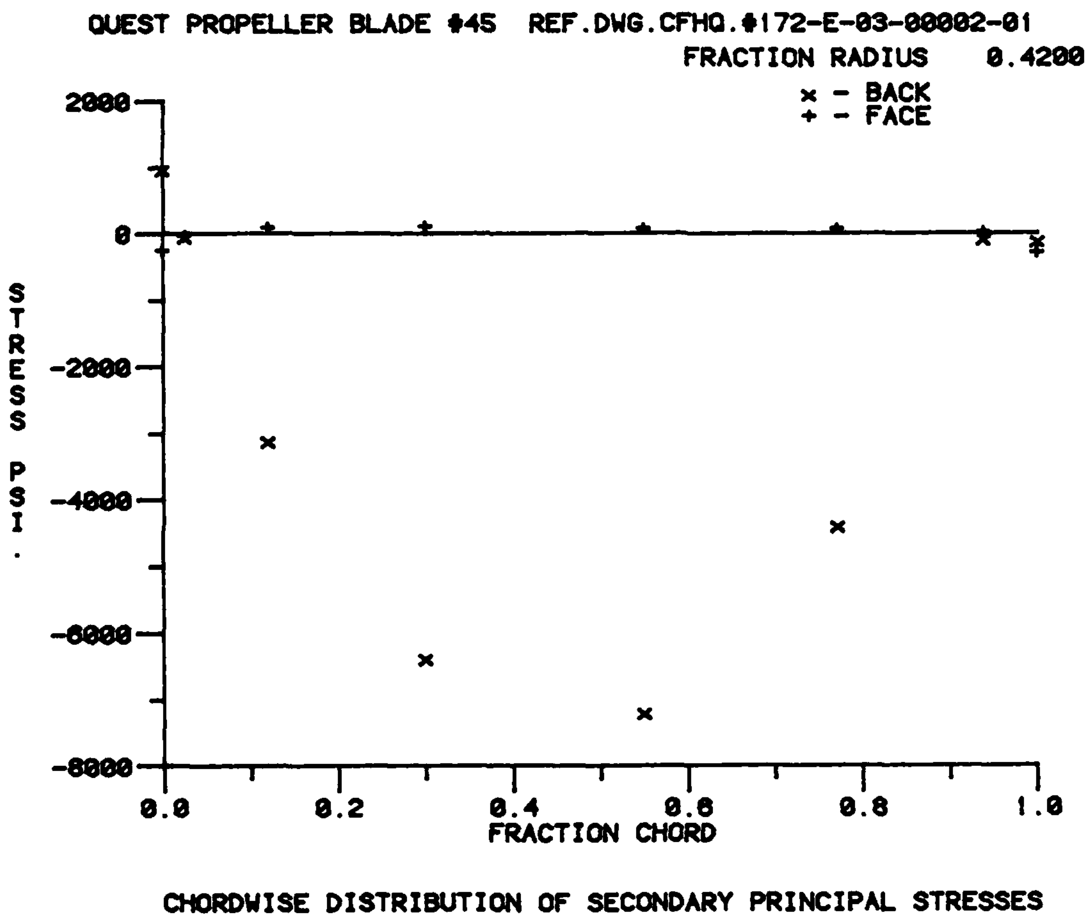


FIG. 38 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.42 FRACTION OF FULL RADIUS

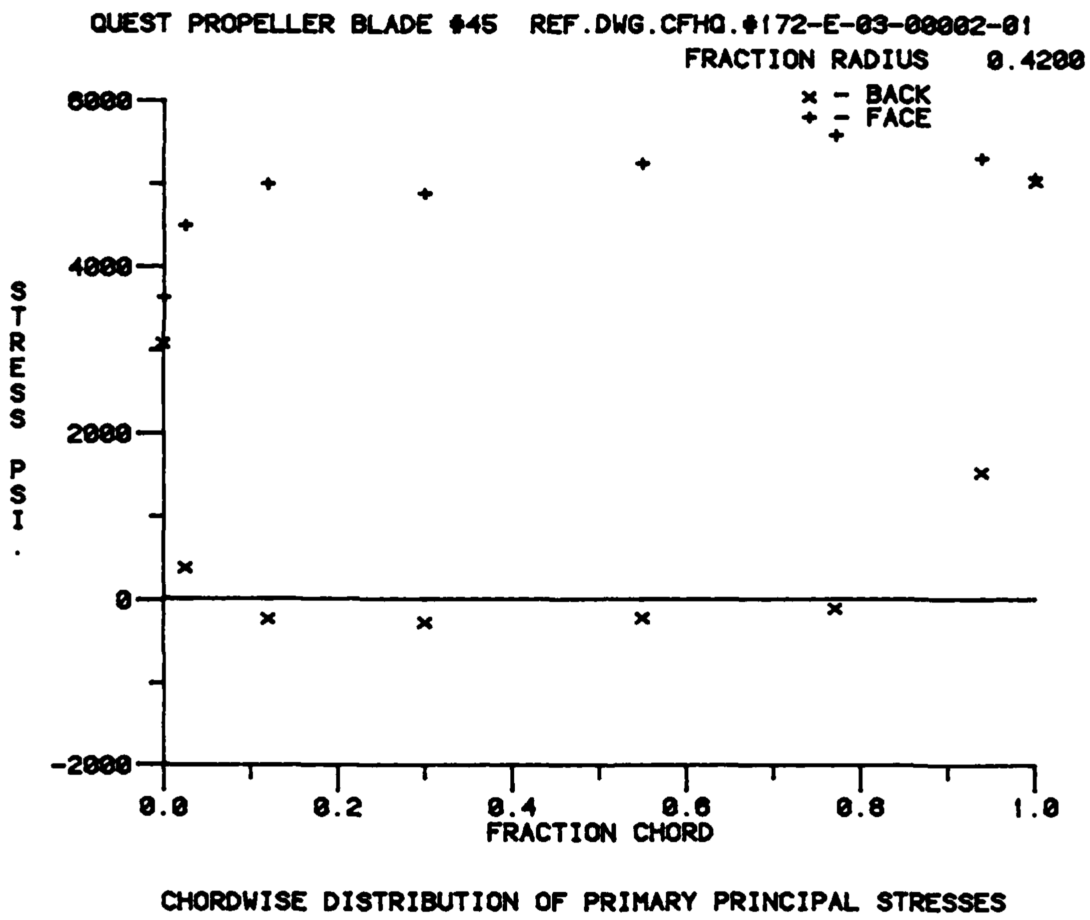


FIG. 37 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.42 FRACTION OF FULL RADIUS

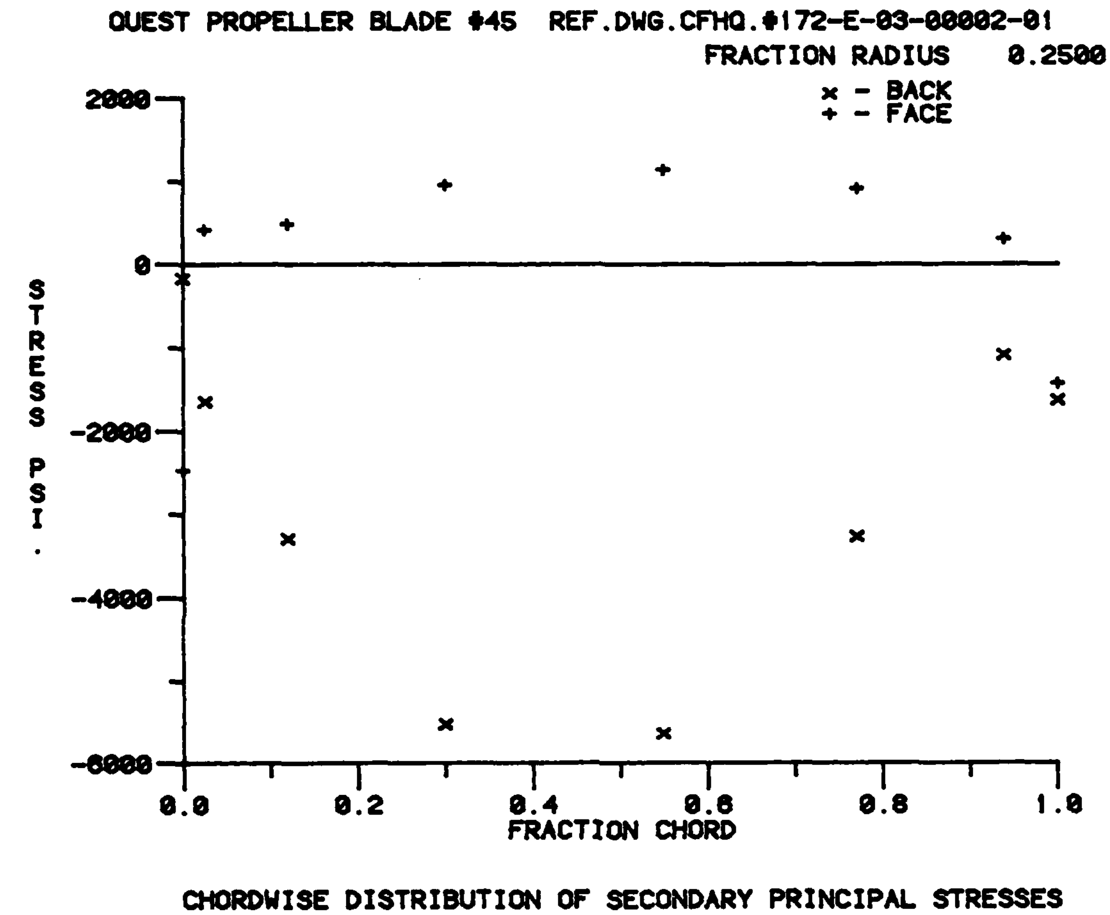


FIG. 36 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.25 FRACTION OF FULL RADIUS

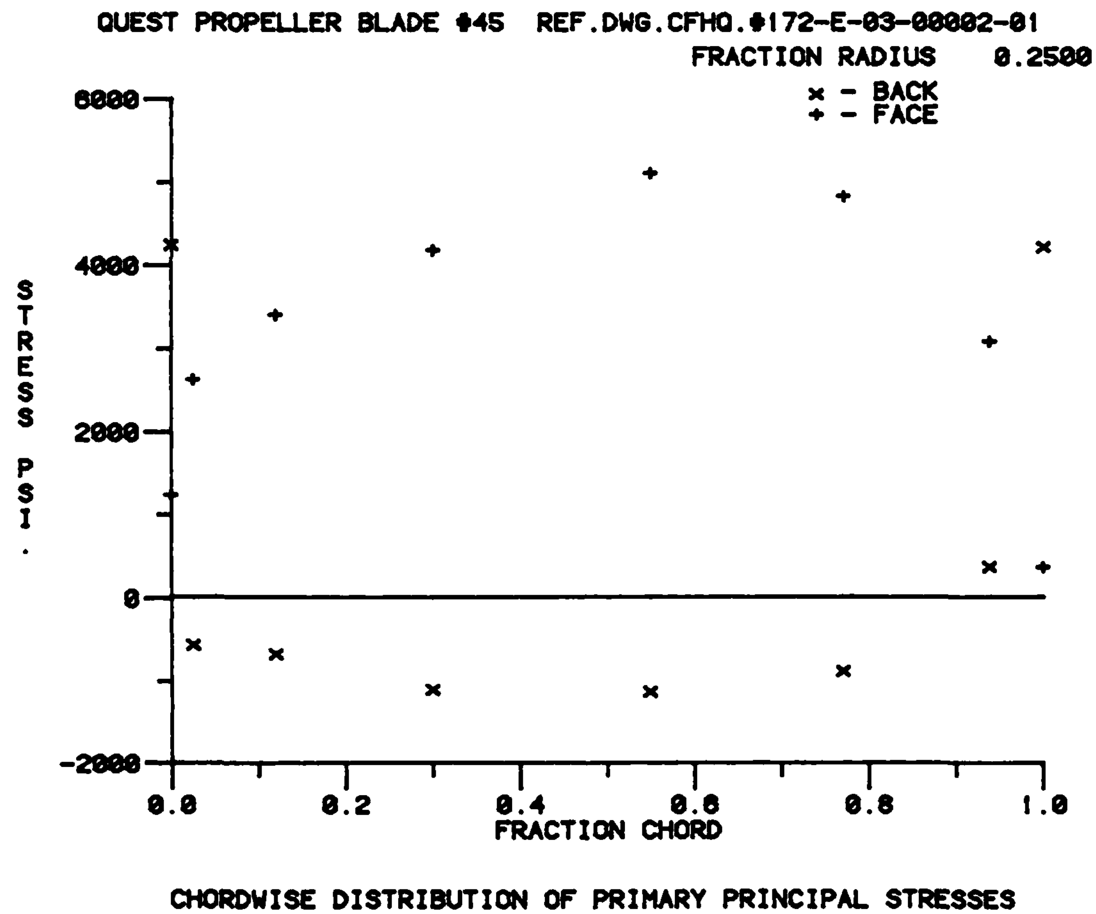


FIG. 35 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.25 FRACTION OF FULL RADIUS

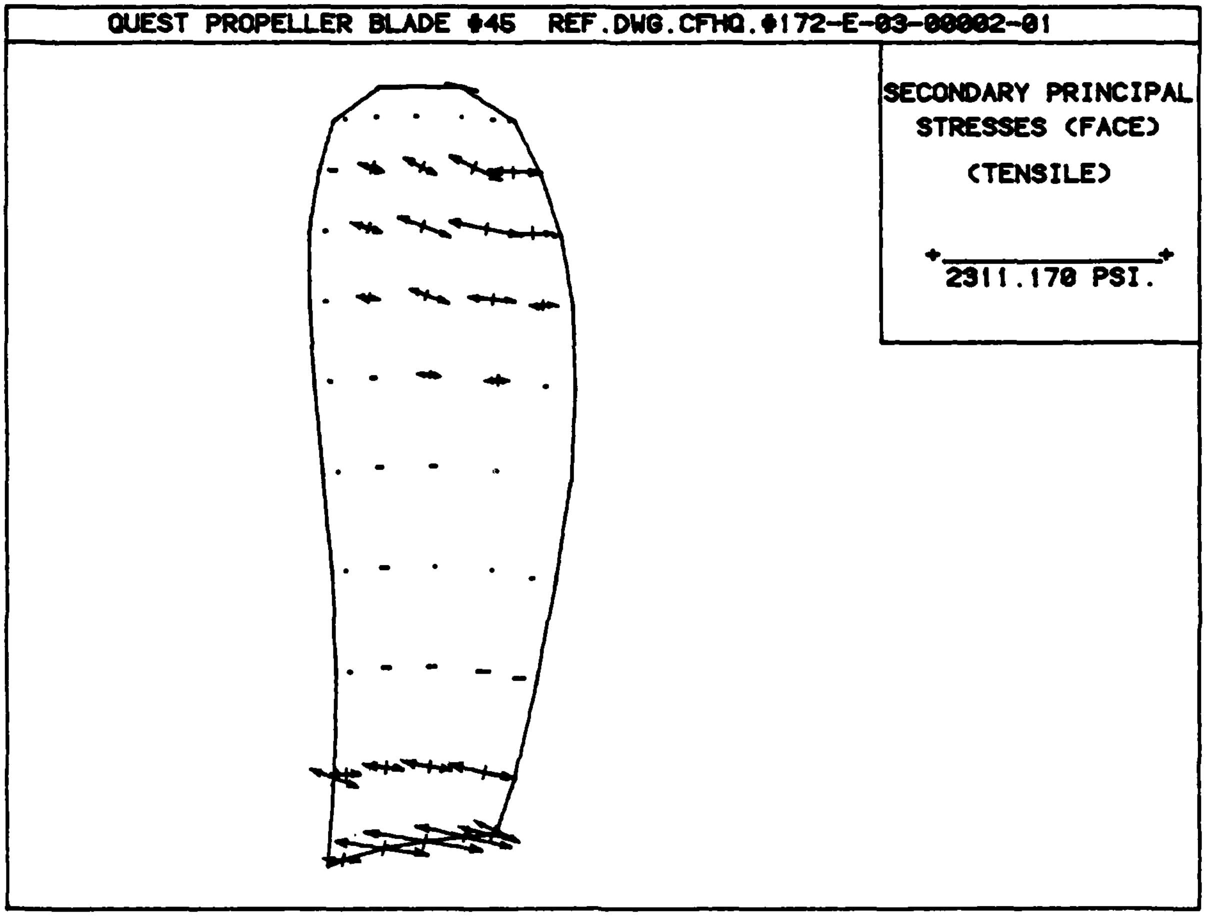


FIG. 34 SECONDARY PRINCIPAL STRESS DIRECTIONS FOR THE FACE OF THE NRC 45 BLADE

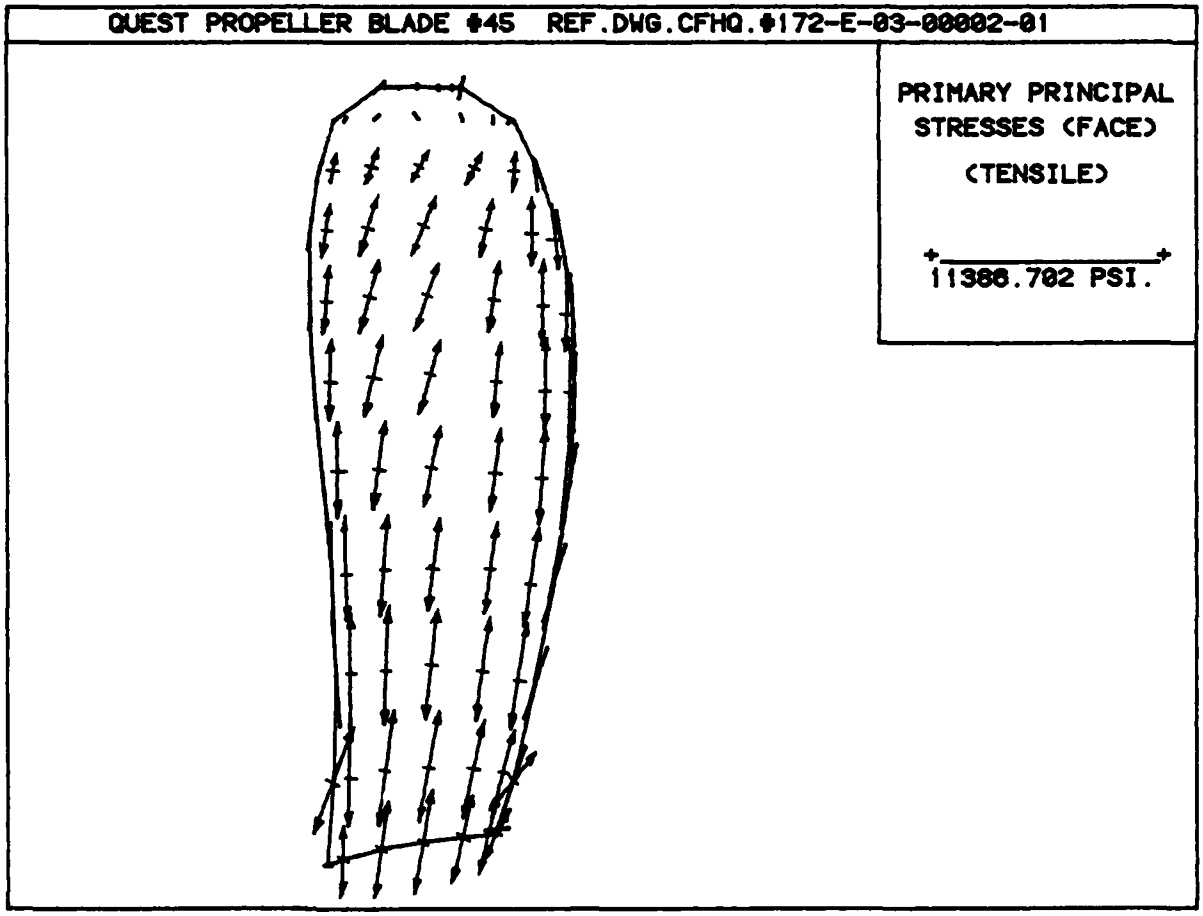


FIG. 33 PRIMARY PRINCIPAL STRESS DIRECTIONS FOR THE FACE OF THE NRC 45 BLADE

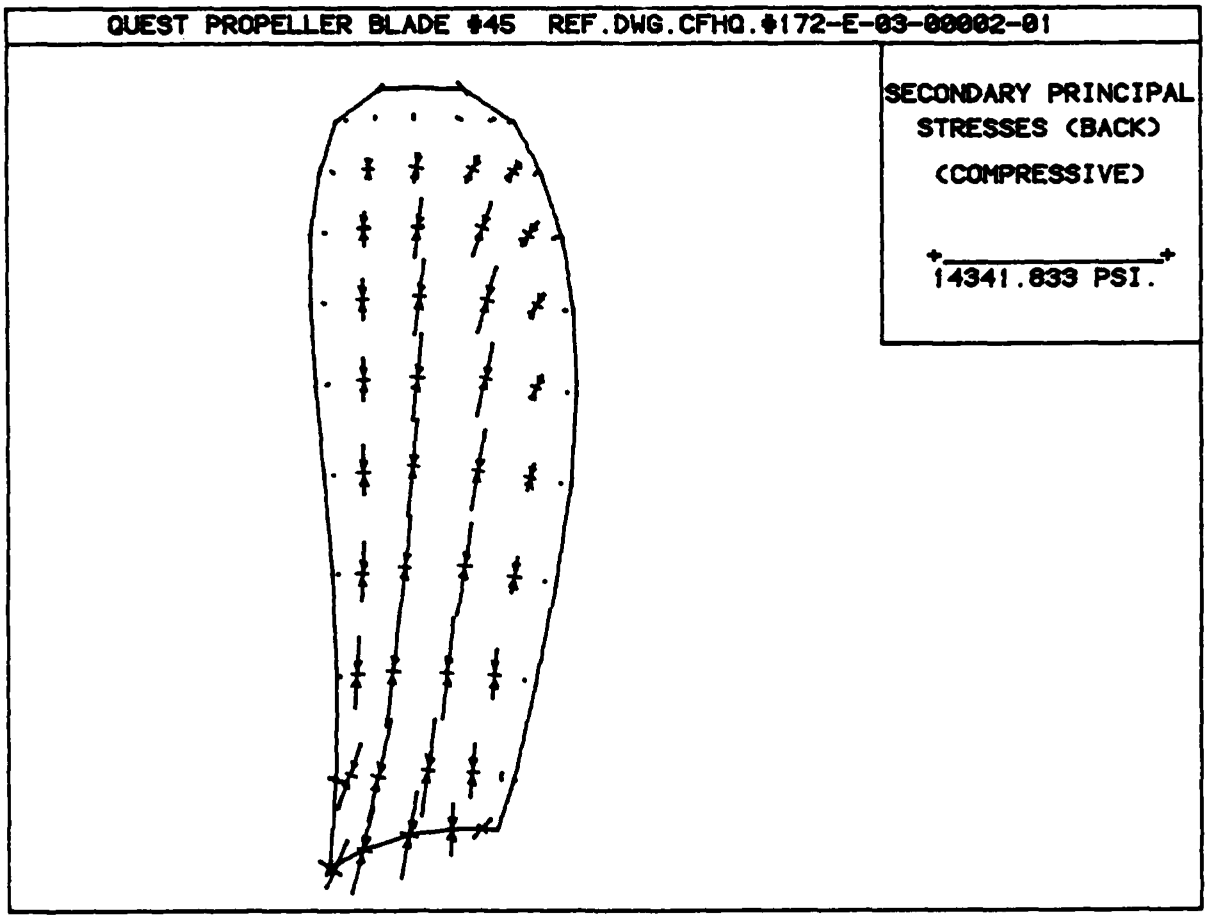


FIG. 32 SECONDARY PRINCIPAL STRESS DIRECTIONS FOR THE BACK OF THE NRC 45 BLADE

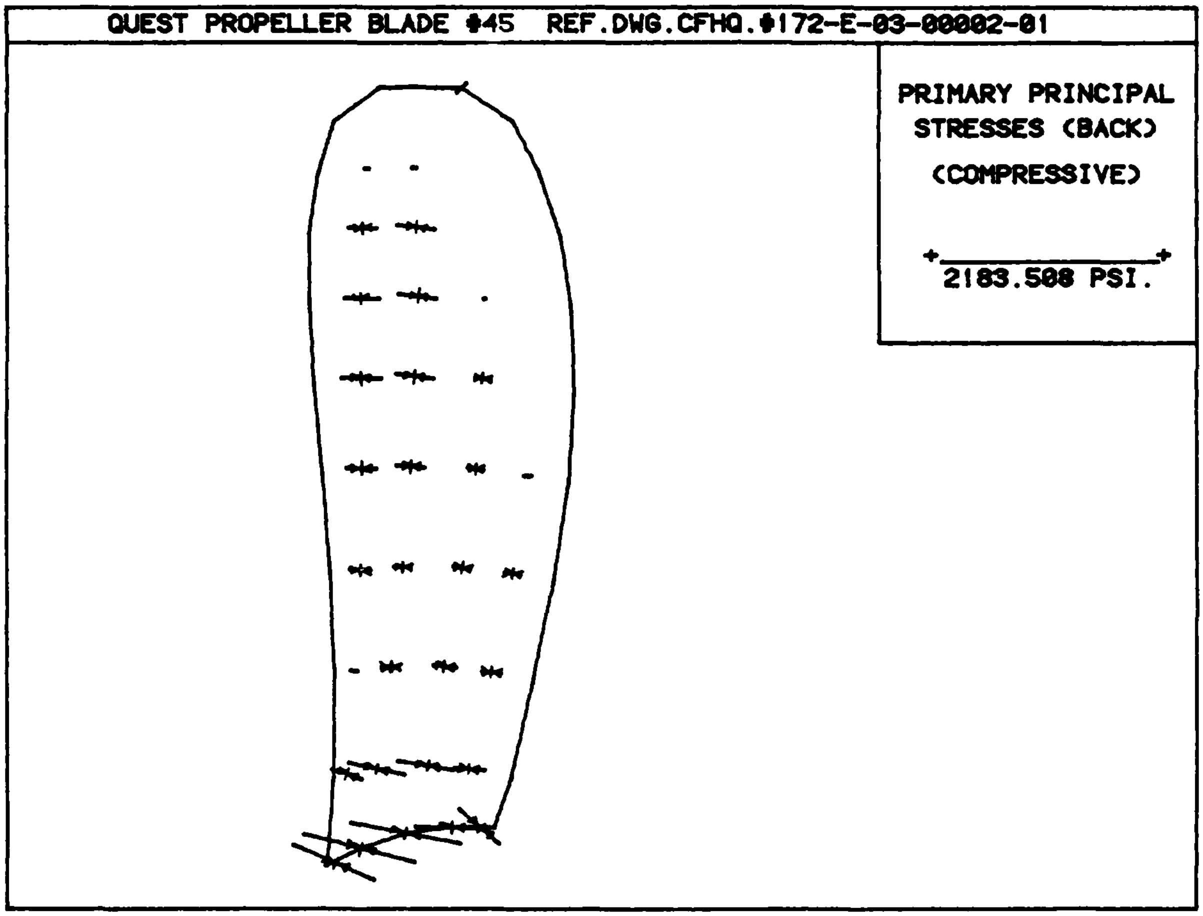


FIG. 31 PRIMARY PRINCIPAL STRESS VECTORS FOR THE BACK OF THE NRC 45 BLADE

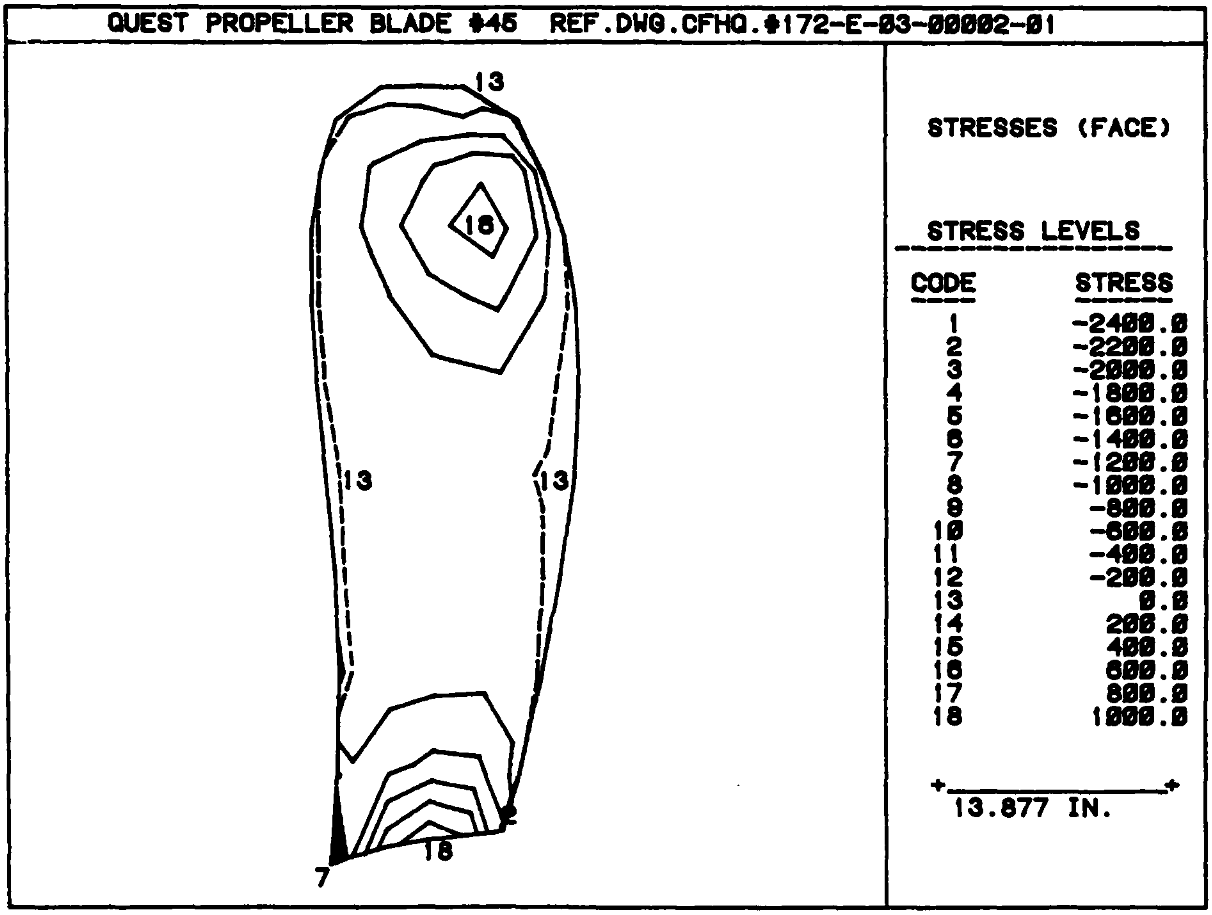


FIG. 30 SECONDARY PRINCIPAL STRESS CONTOURS ON FACE OF NRC 45 PROPELLER BLADE

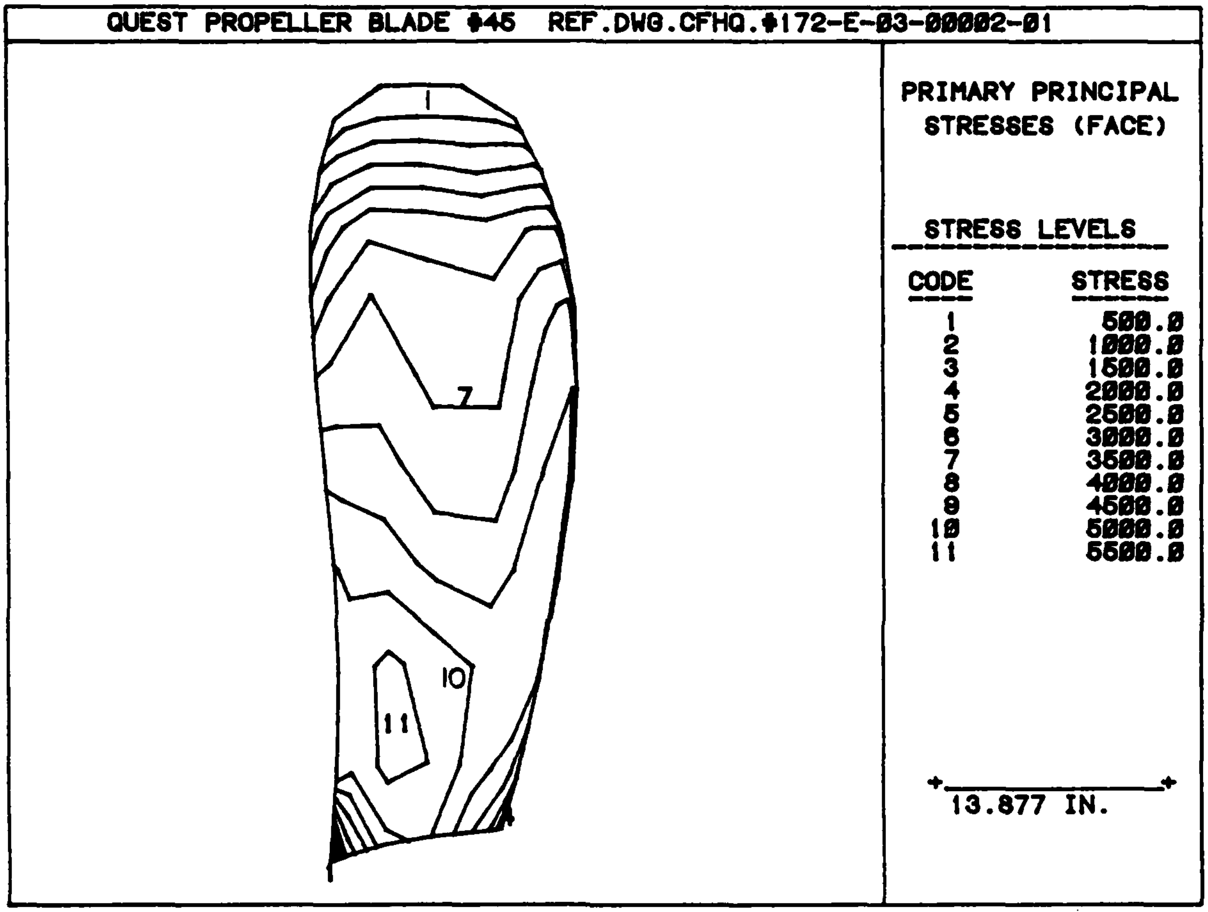


FIG. 29 PRIMARY PRINCIPAL STRESS CONTOURS ON FACE OF NRC 45 PROPELLER BLADE

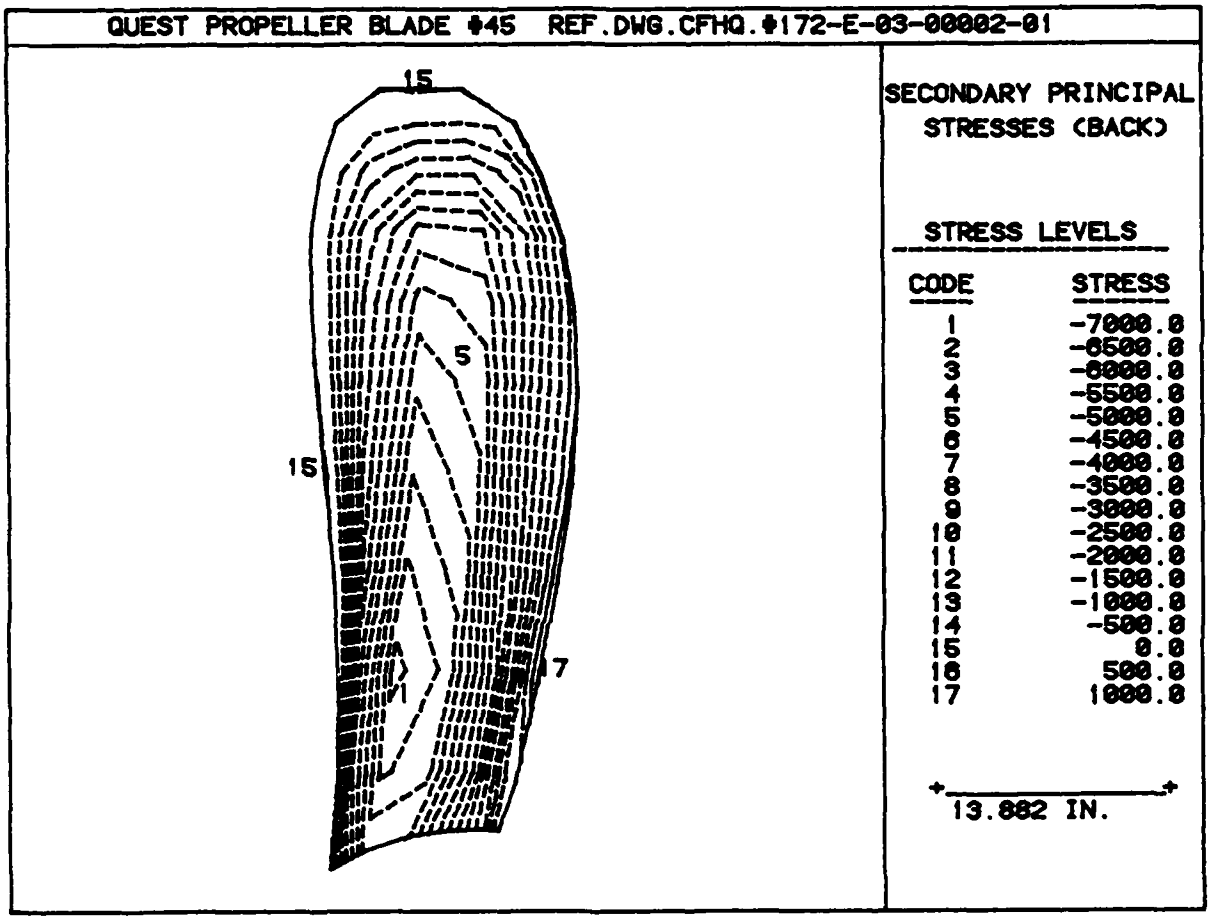


FIG. 28 SECONDARY PRINCIPAL STRESS CONTOURS ON BACK OF NRC 45 PROPELLER BLADE

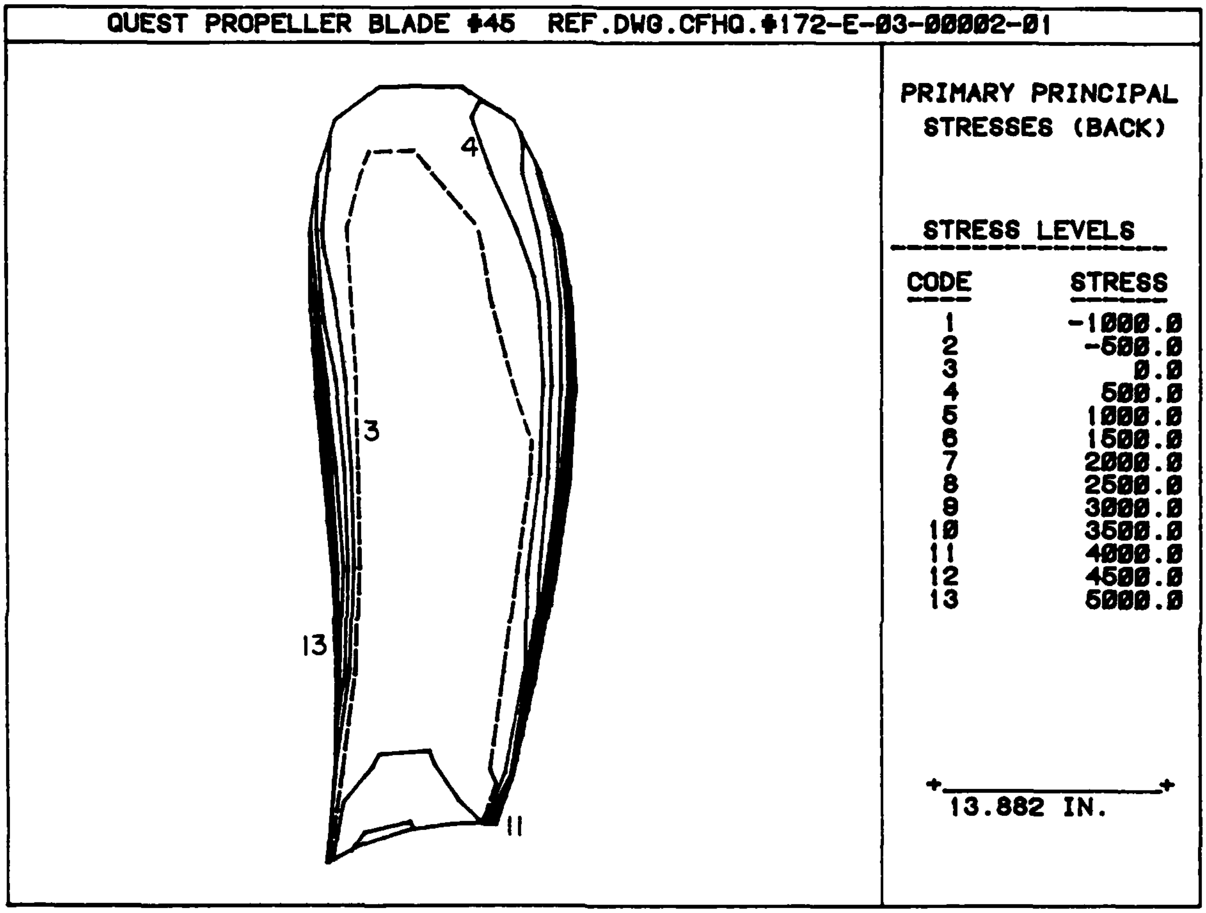


FIG. 27 PRIMARY PRINCIPAL STRESS CONTOURS ON BACK OF NRC 45 PROPELLER BLADE

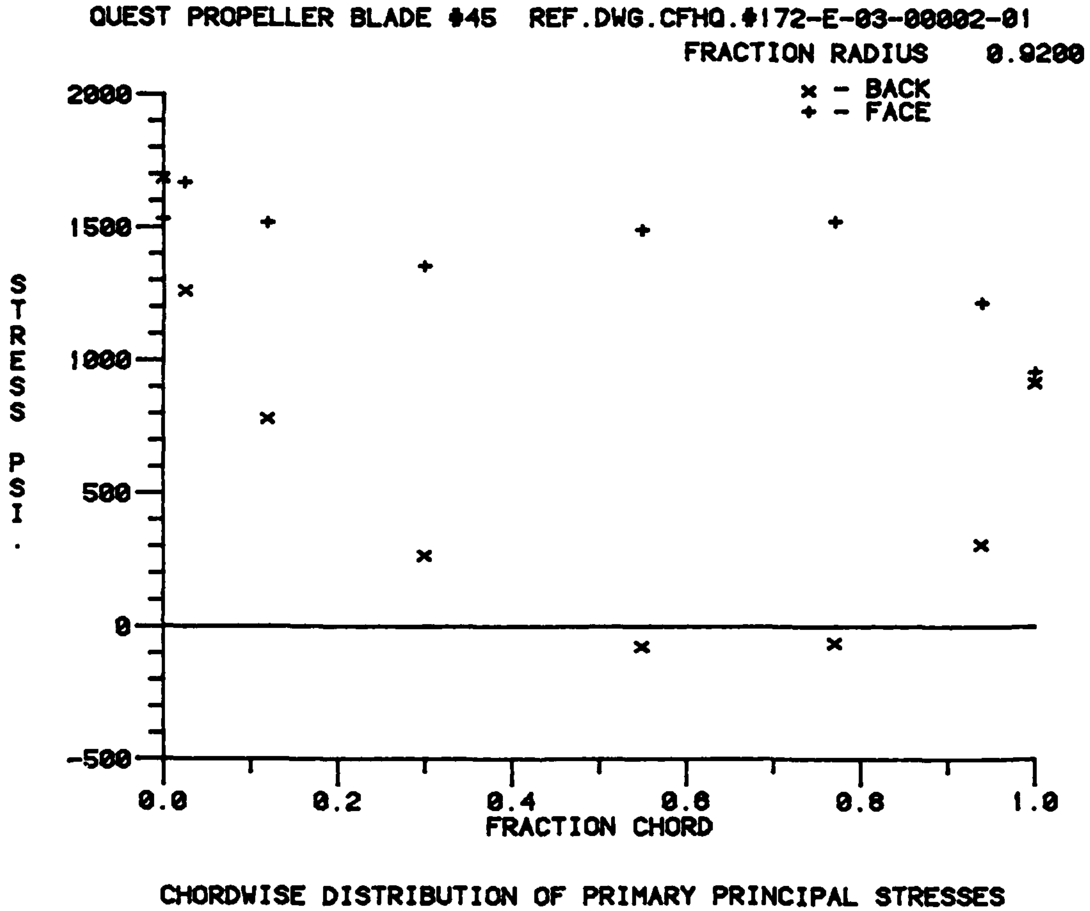


FIG. 41 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.92 FRACTION OF FULL RADIUS

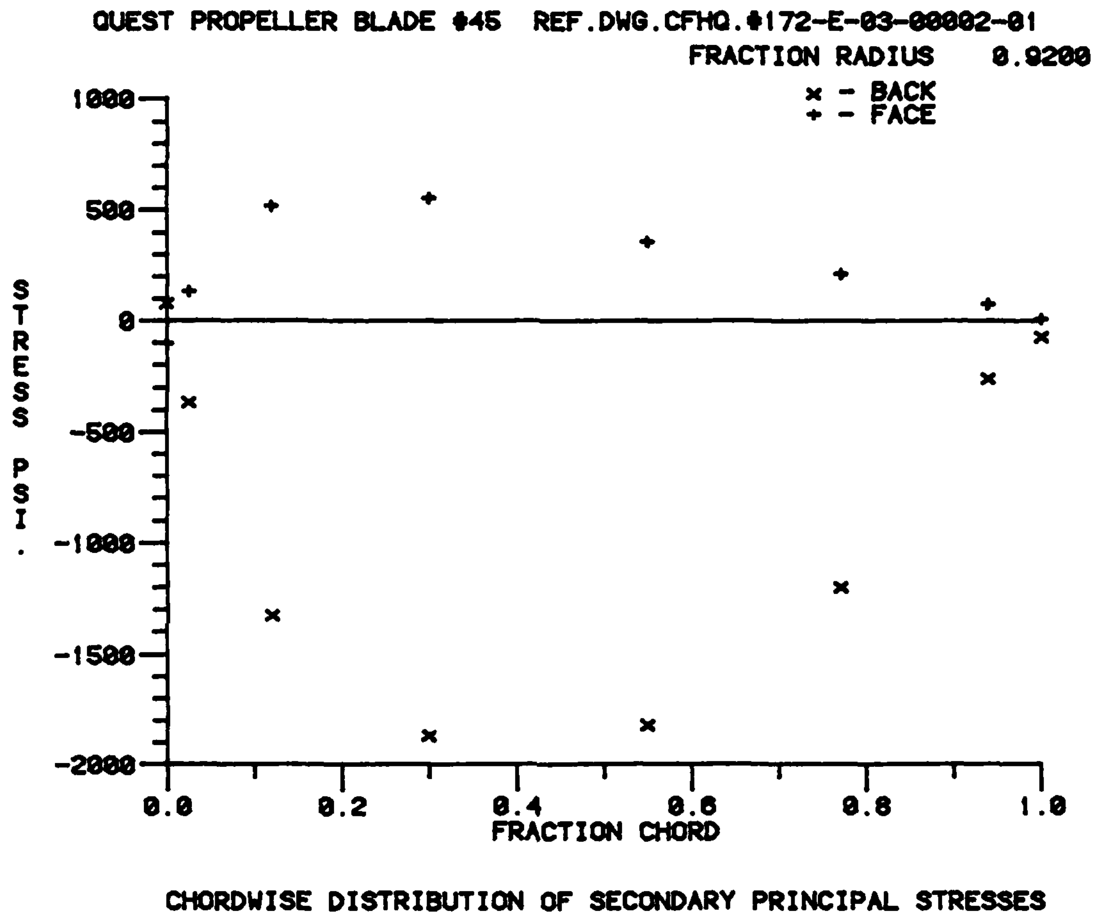


FIG. 42 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.92 FRACTION OF FULL RADIUS

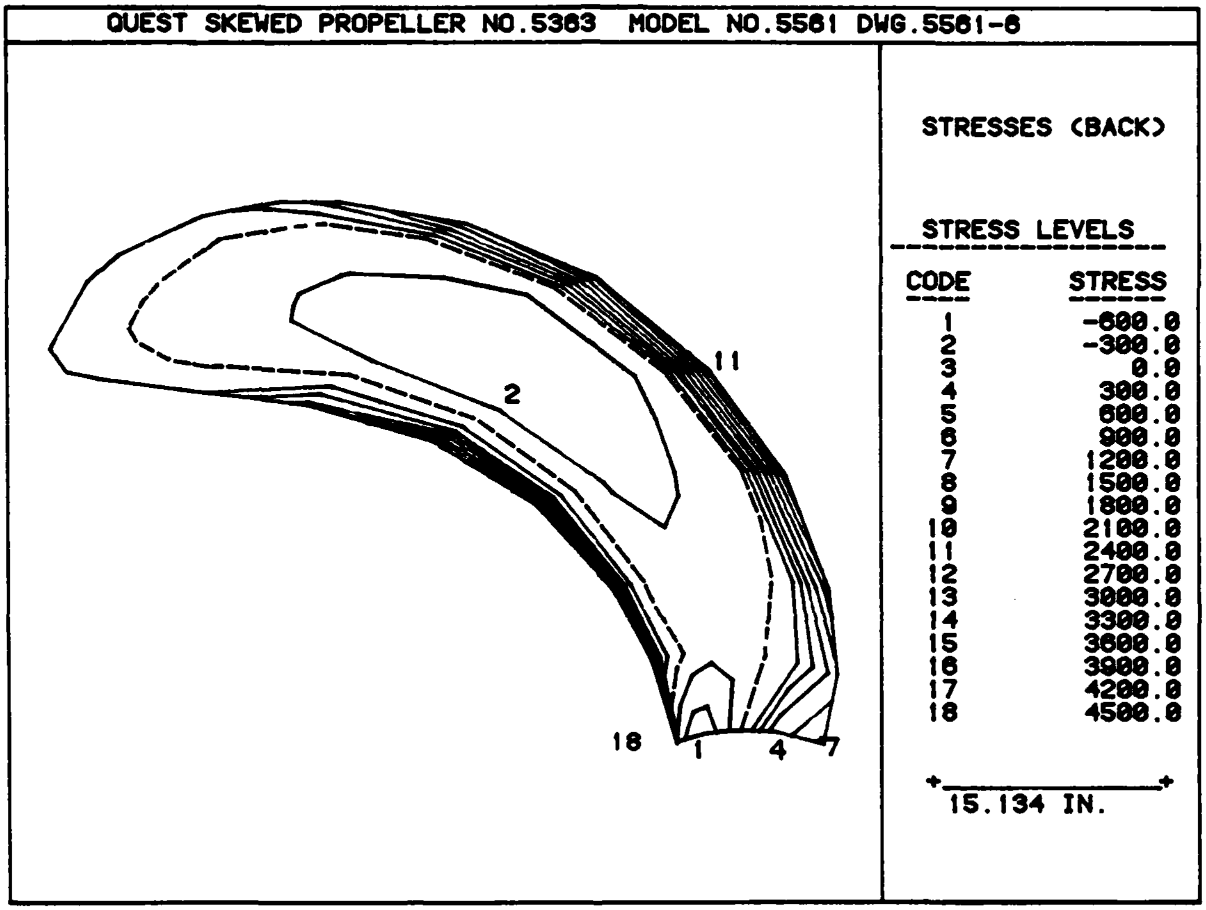


FIG. 43 PRIMARY PRINCIPAL STRESS CONTOURS ON BACK OF BLADE UNDER COMBINED LOADING

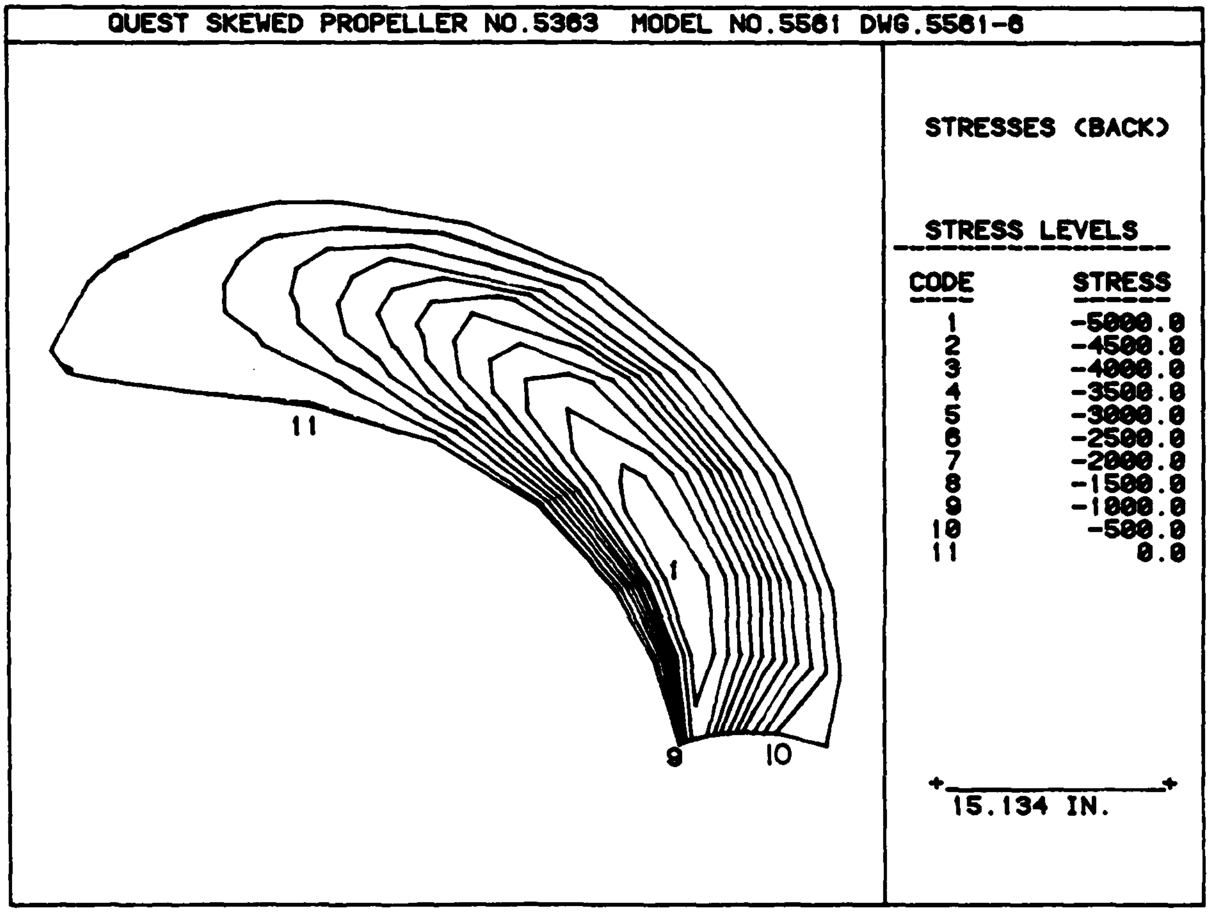
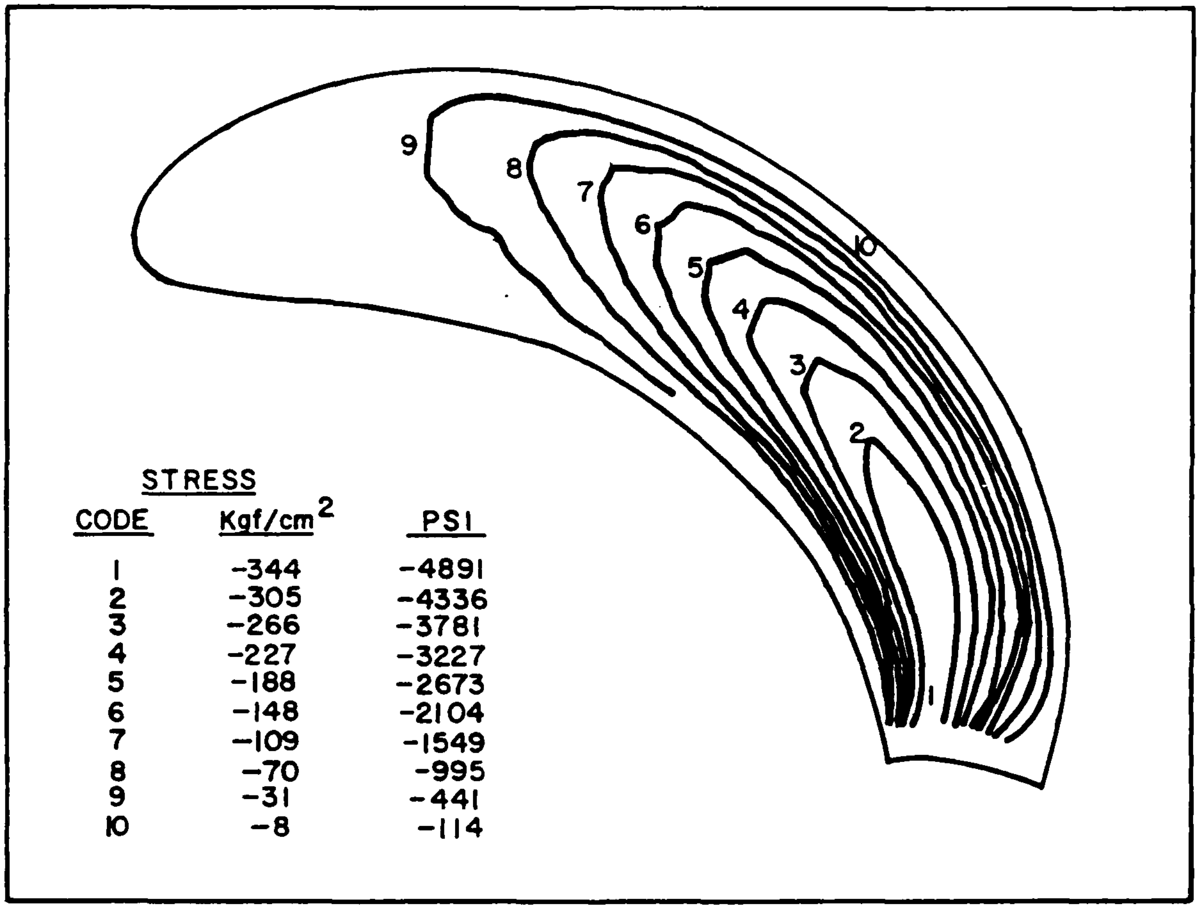


FIG. 44 SECONDARY PRINCIPAL STRESS ON BACK OF BLADE UNDER COMBINED LOADING



STRESS CODE	Kgf/cm^2	PSI
1	-344	-4891
2	-305	-4336
3	-266	-3781
4	-227	-3227
5	-188	-2673
6	-148	-2104
7	-109	-1549
8	-70	-995
9	-31	-441
10	-8	-114

FIG. 45 NSMB RESULTS FOR SECONDARY PRINCIPAL STRESS CONTOURS ON BACK OF BLADE UNDER COMBINED LOAD

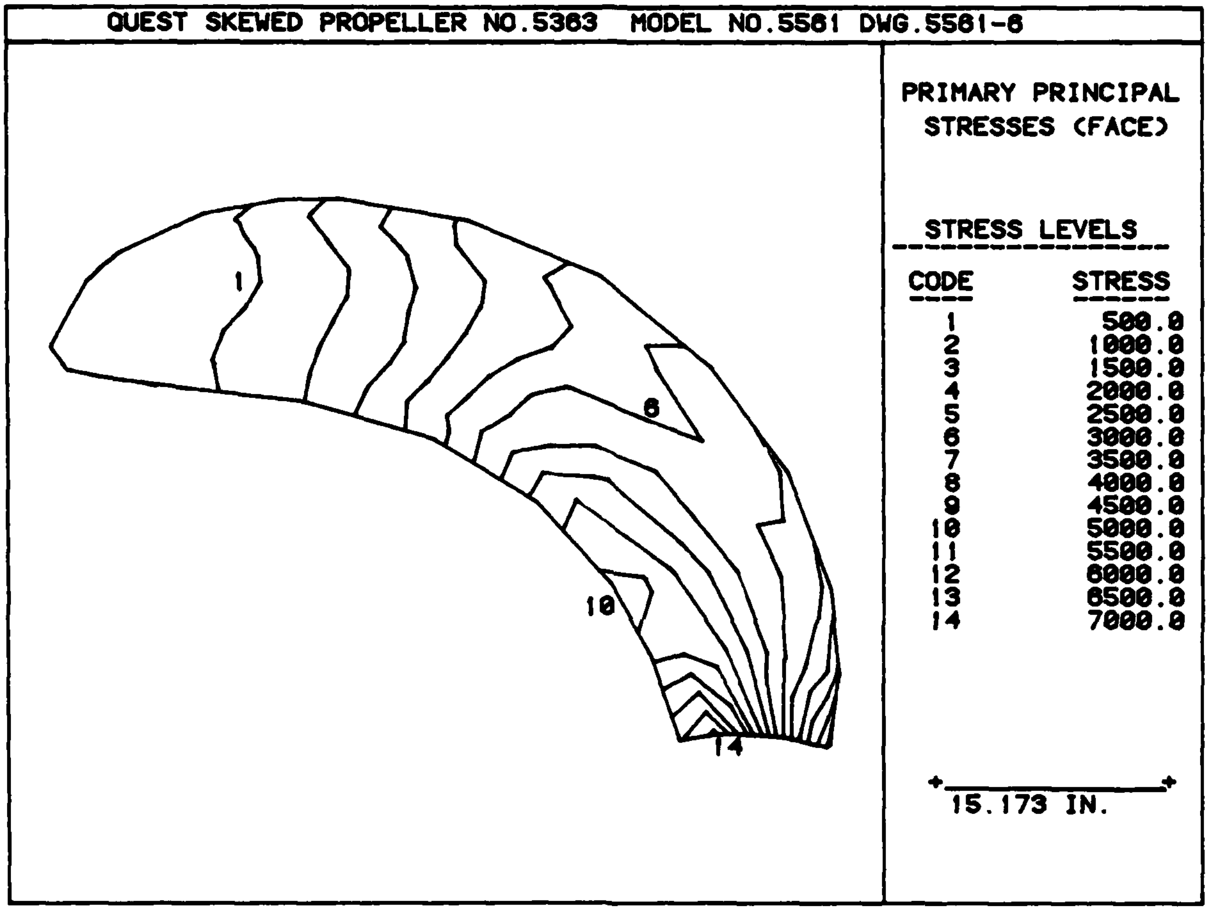


FIG. 46 PRIMARY PRINCIPAL STRESS CONTOURS ON FACE OF BLADE UNDER COMBINED LOAD

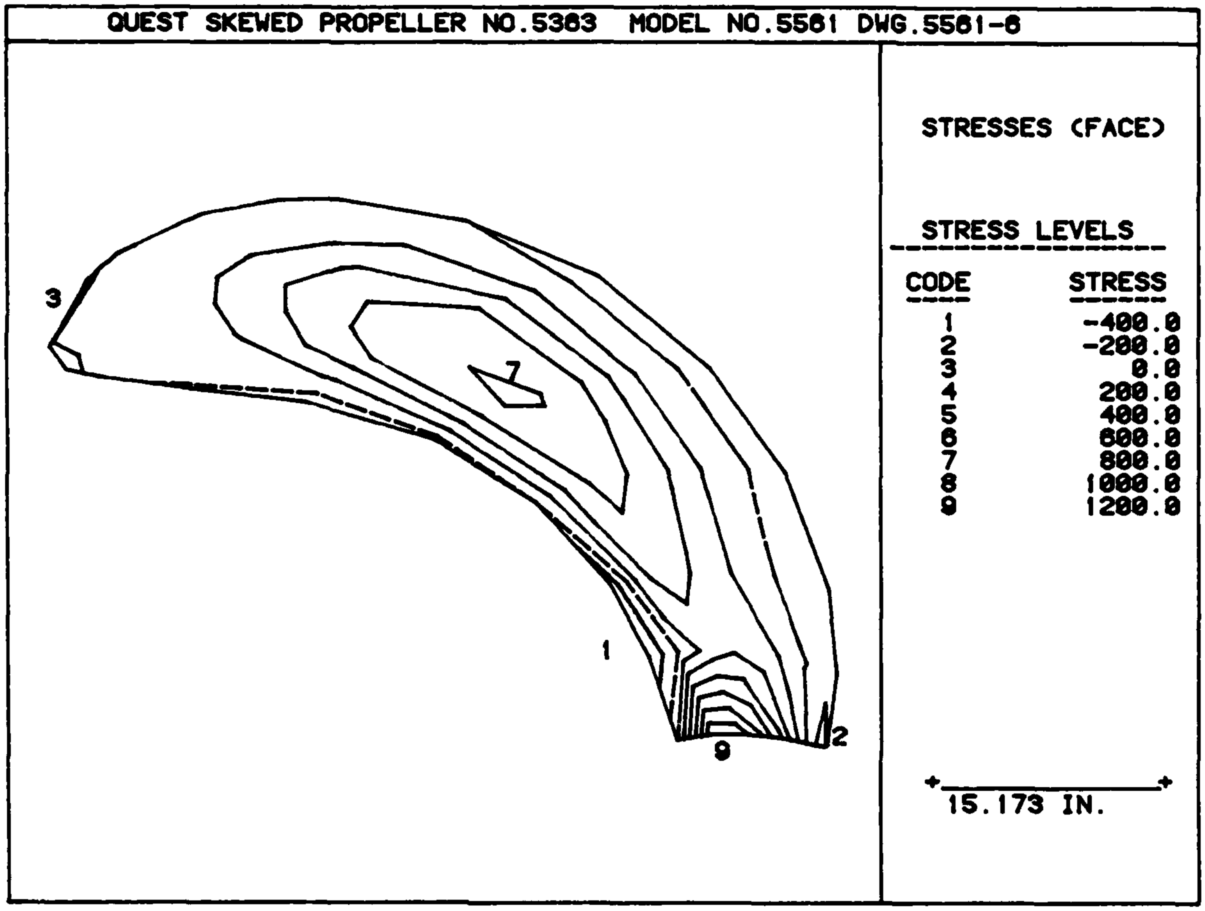


FIG. 47 SECONDARY PRINCIPAL STRESS CONTOURS ON FACE OF BLADE UNDER COMBINED LOAD

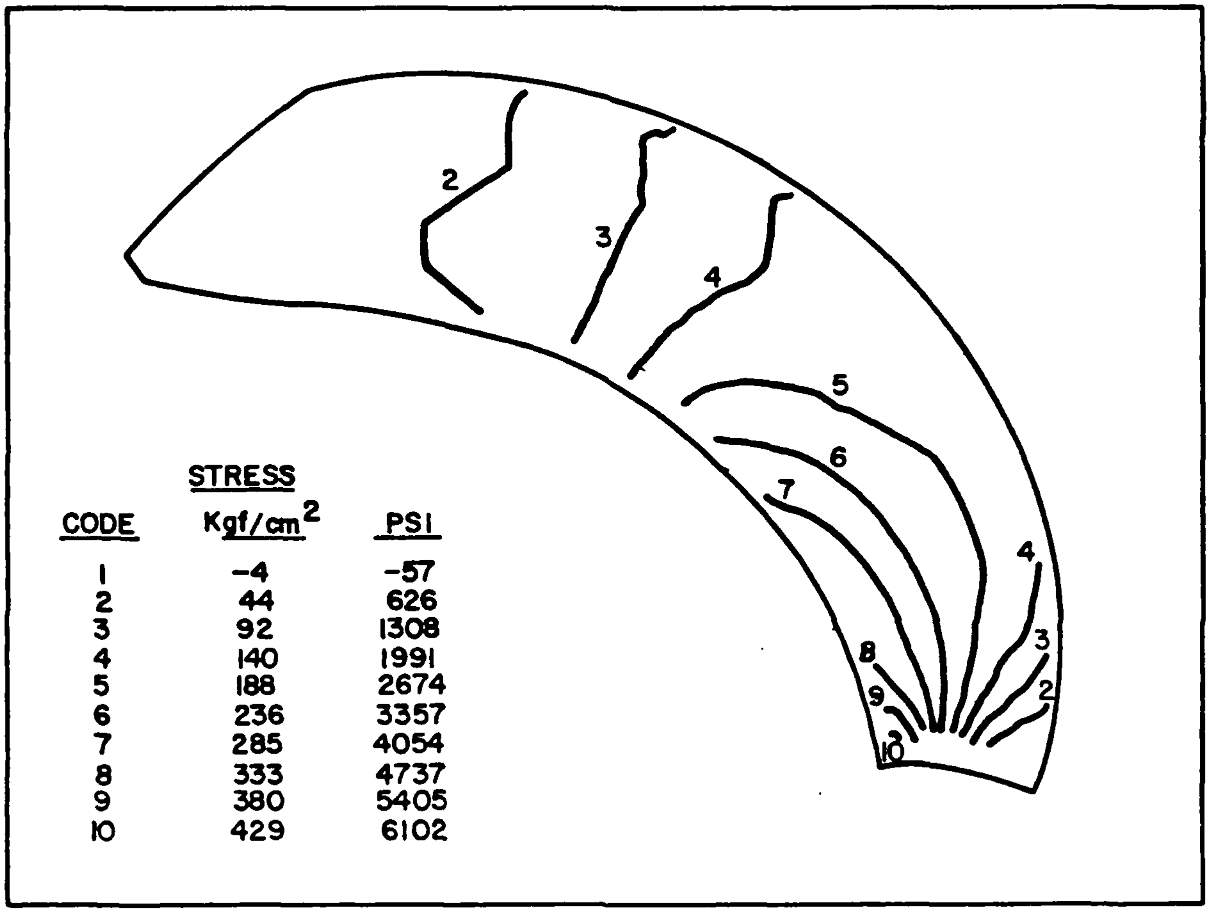


FIG. 48 NSMB RESULTS FOR PRIMARY PRINCIPAL STRESS CONTOURS ON FACE OF BLADE UNDER COMBINED LOAD

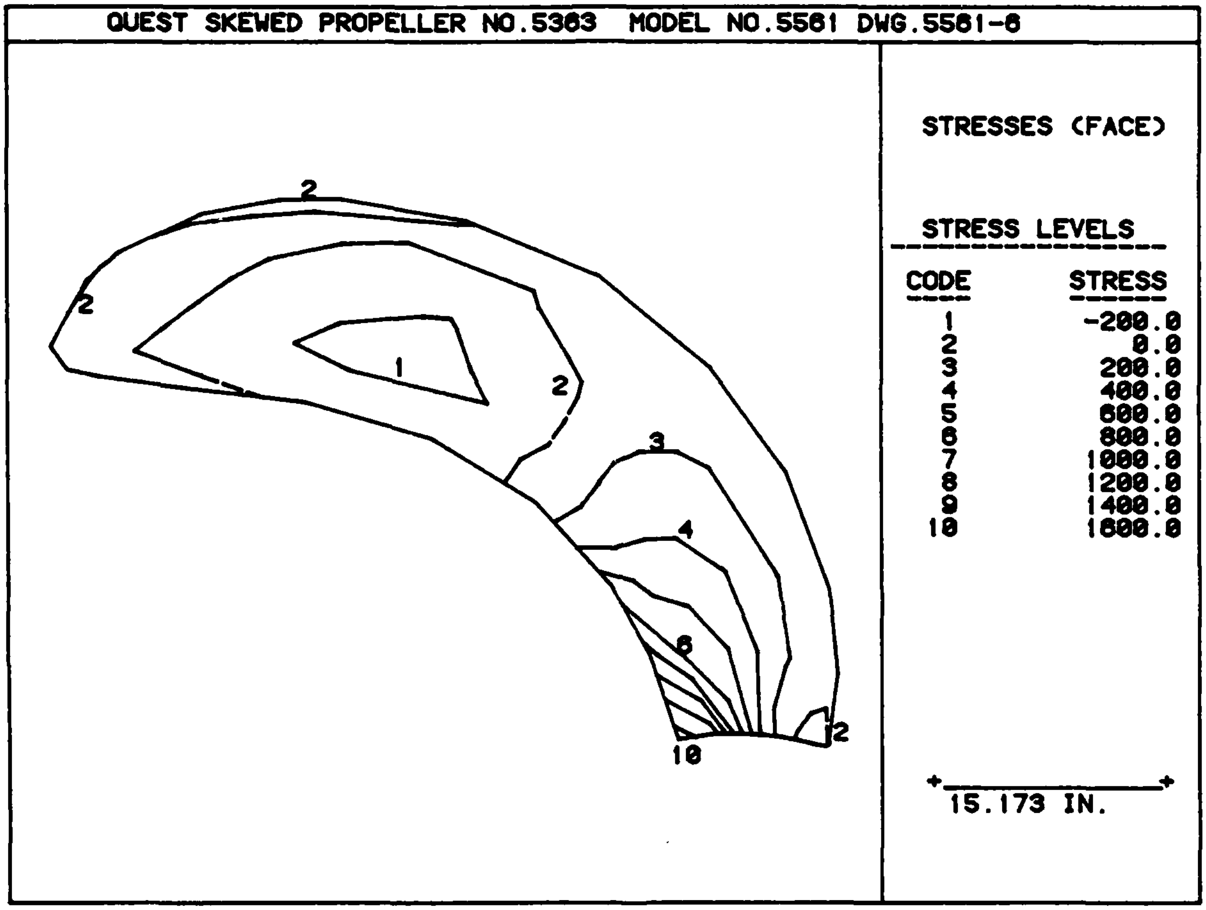


FIG. 49 PRIMARY PRINCIPAL STRESS CONTOURS ON FACE OF BLADE UNDER CENTRIFUGAL LOAD 143 RPM

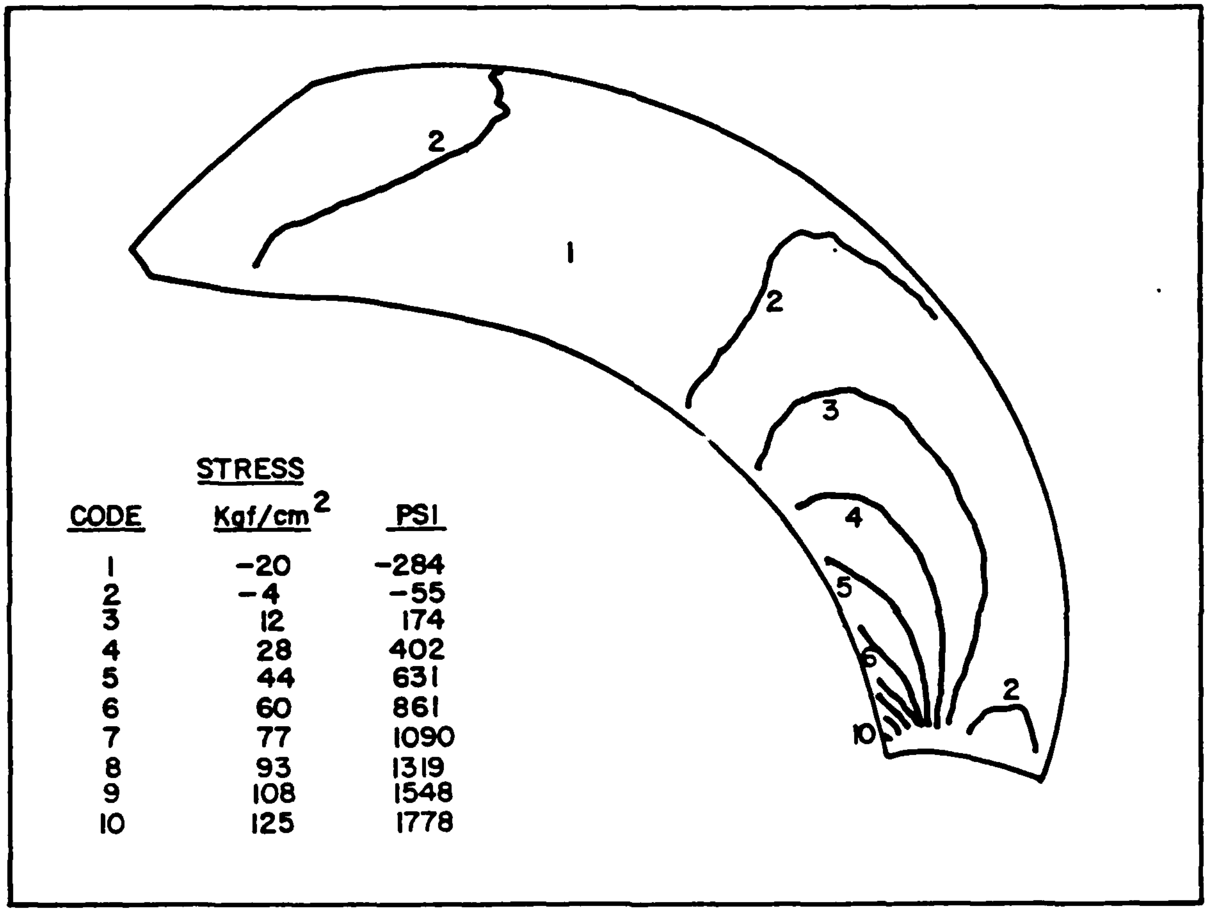


FIG. 50 NSMB RESULTS FOR PRIMARY PRINCIPAL STRESS CONTOURS ON FACE OF BLADE UNDER CENTRIFUGAL LOADS AT 143 RPM

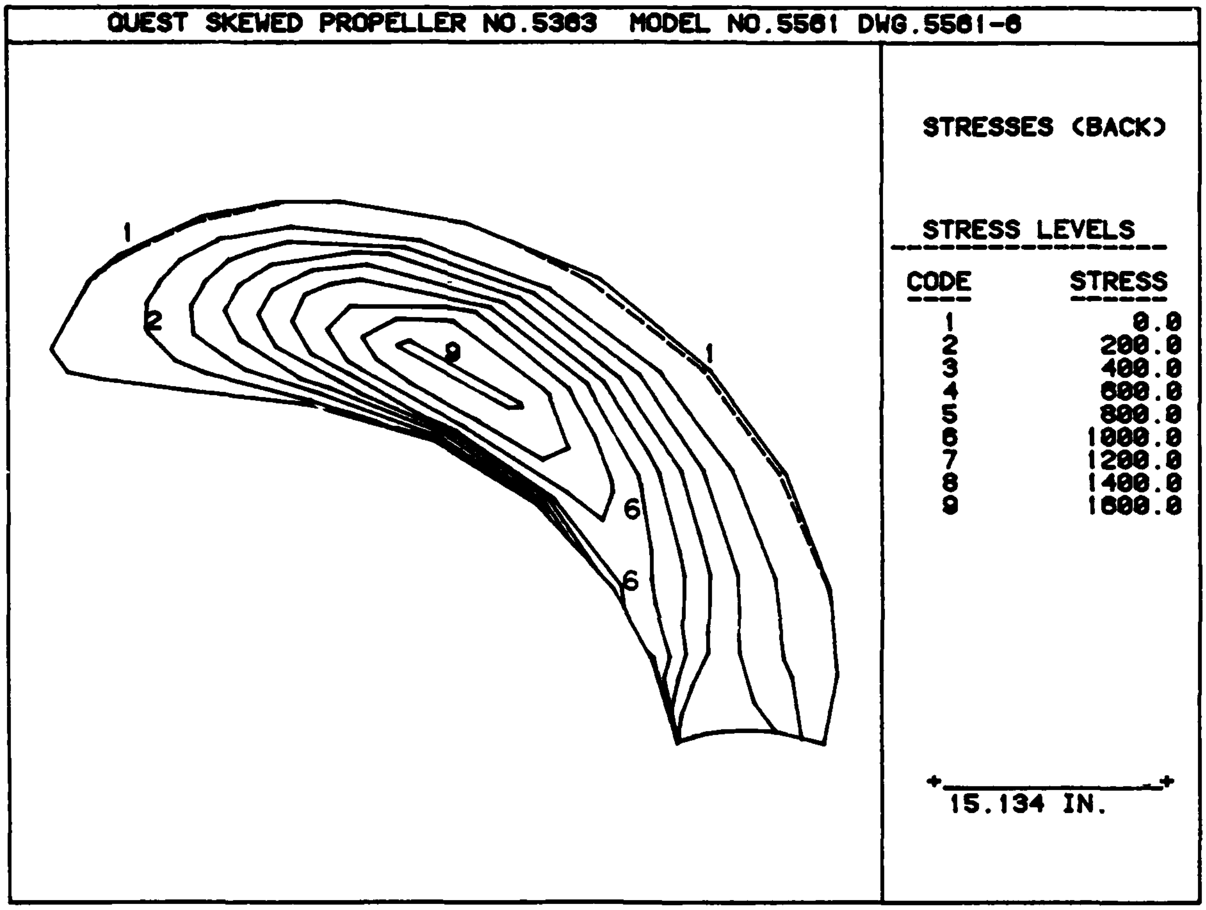


FIG. 51 PRIMARY PRINCIPAL STRESS CONTOURS ON BACK OF BLADE UNDER CENTRIFUGAL LOAD AT 143 RPM

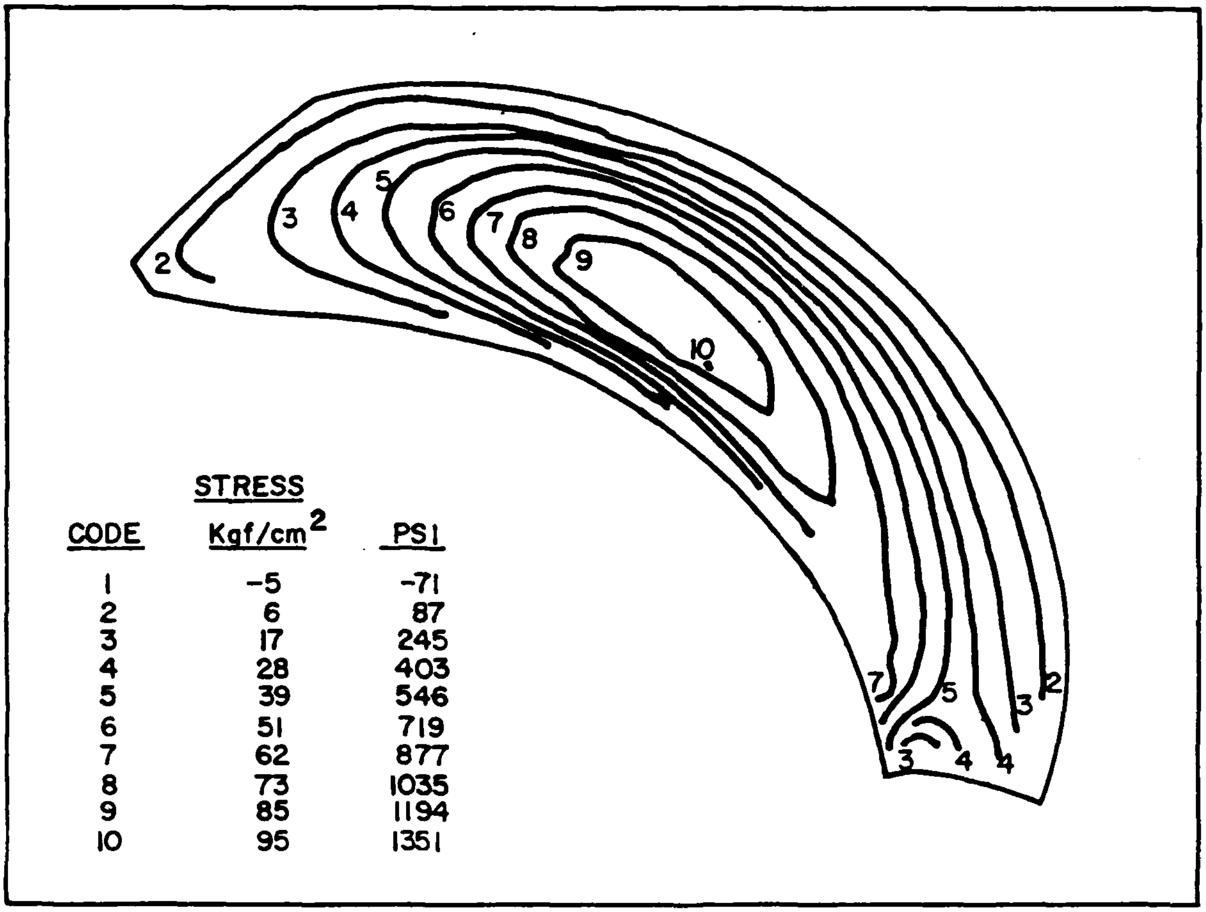


FIG. 52 NSMB RESULTS FOR PRIMARY PRINCIPAL STRESS CONTOURS ON BACK OF BLADE UNDER CENTRIFUGAL LOAD AT 143 RPM

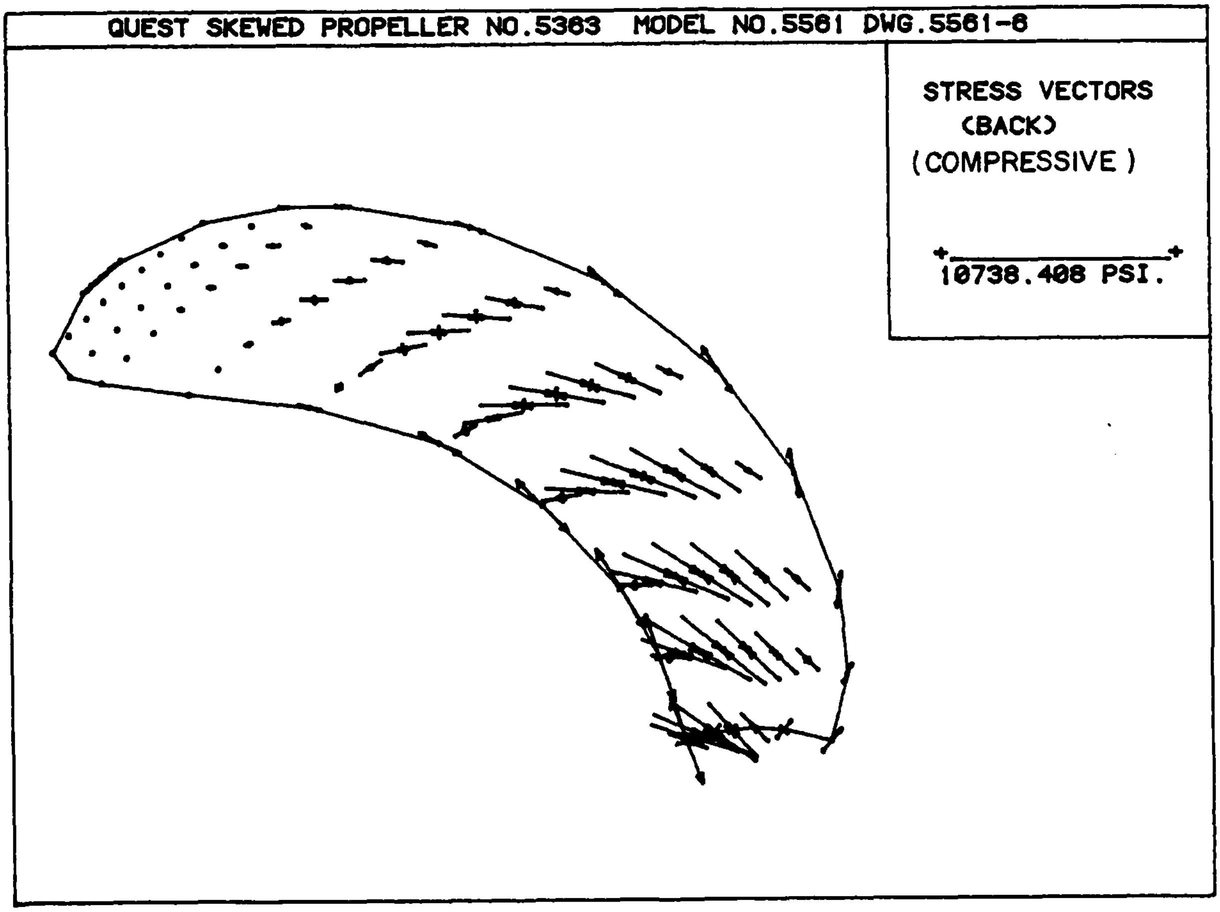


FIG. 53 PRINCIPAL STRESS DIRECTIONS FOR THE BACK OF NSMB 5363 BLADE UNDER COMBINED LOADING

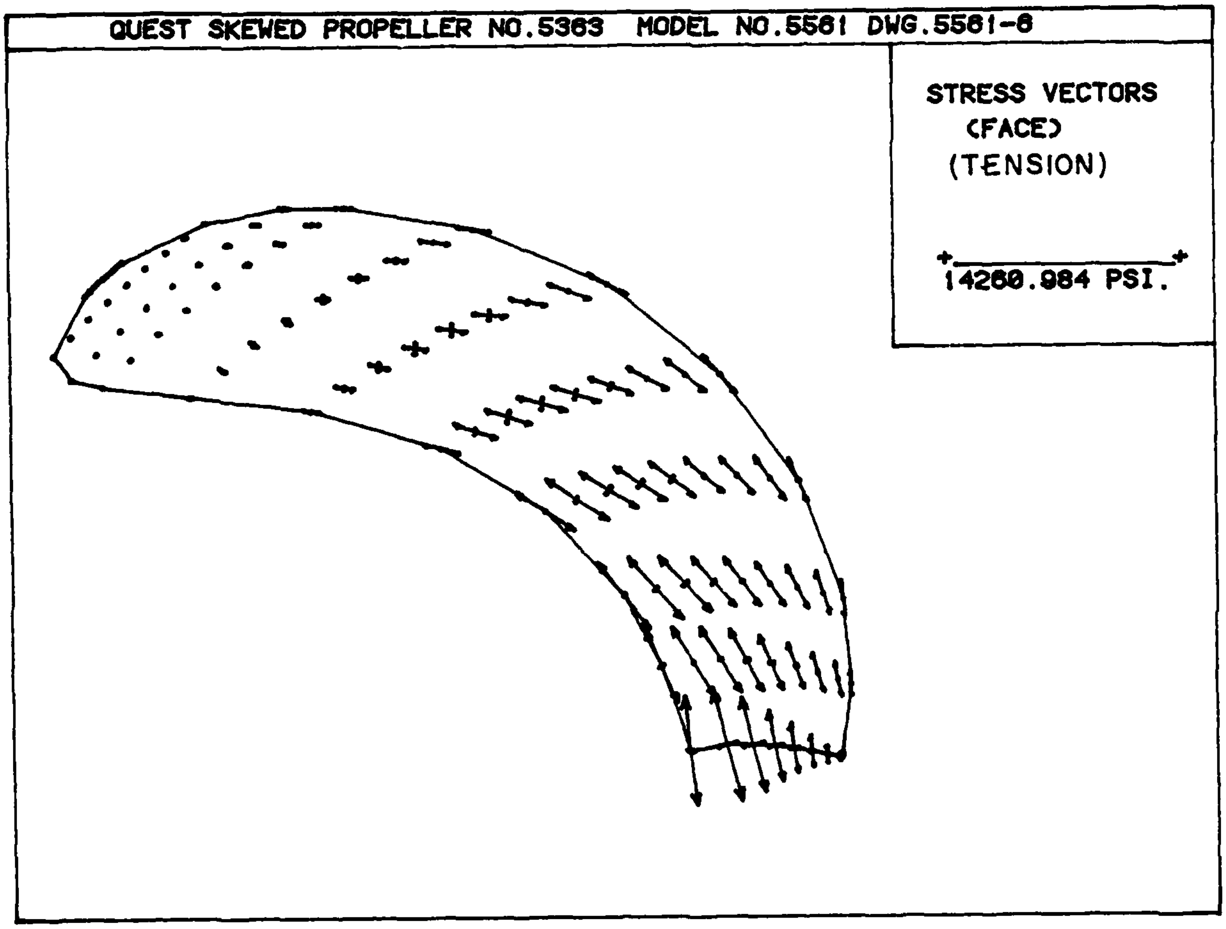


FIG. 54: PRINCIPAL STRESS DIRECTIONS FOR THE FACES OF NSMB 5363 BLADE UNDER COMBINED LOAD

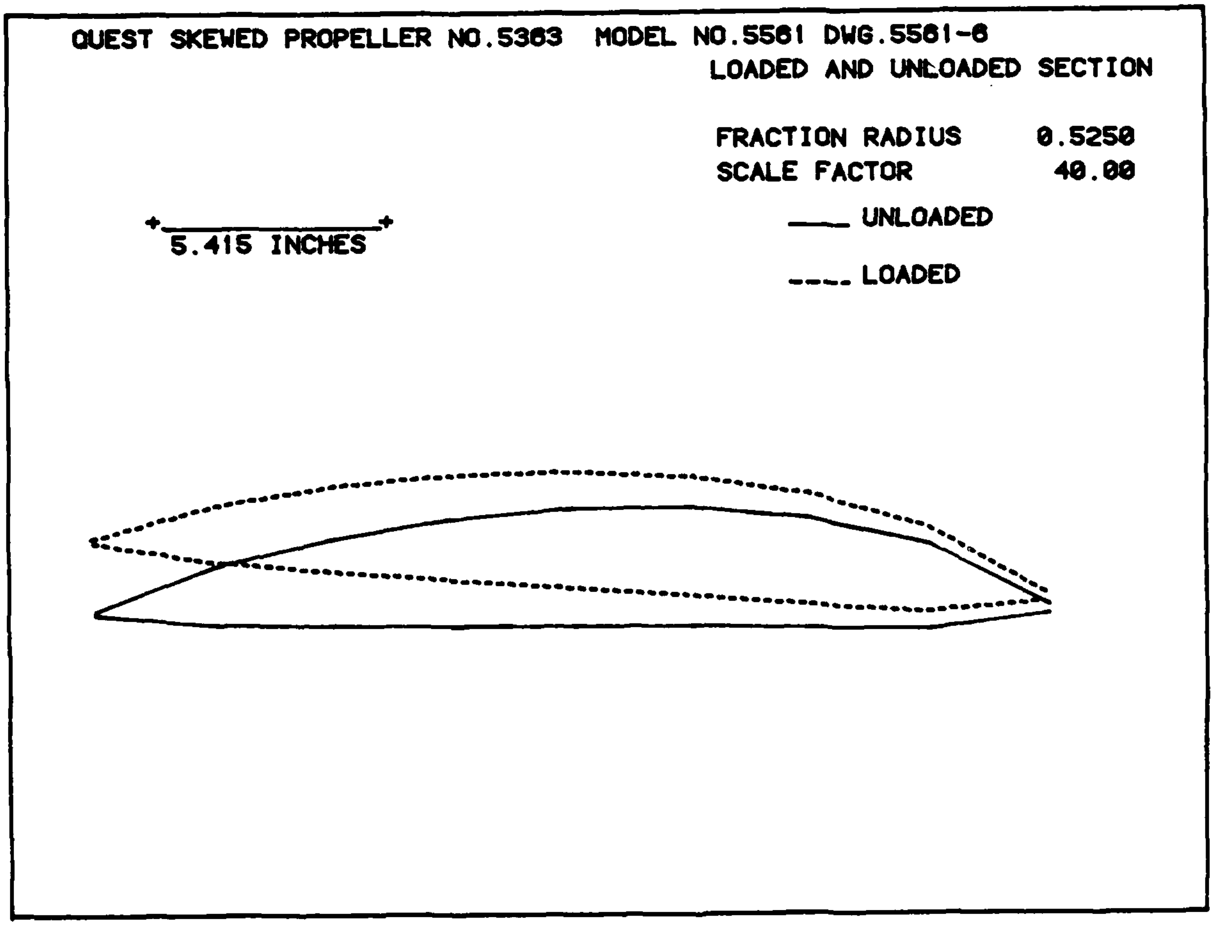


FIG. 68 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.53 FRACTION OF FULL RADIUS

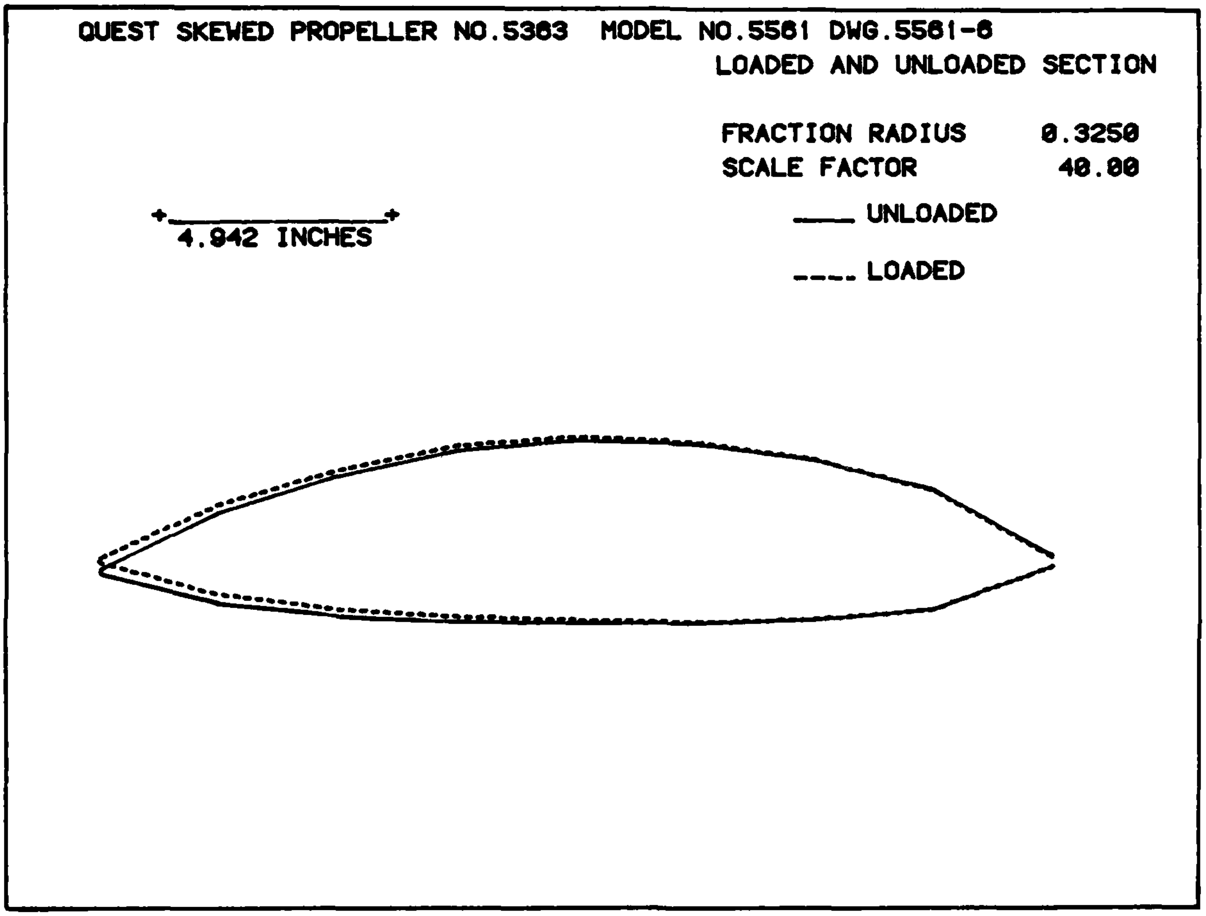


FIG. 67 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.33 FRACTION OF FULL RADIUS

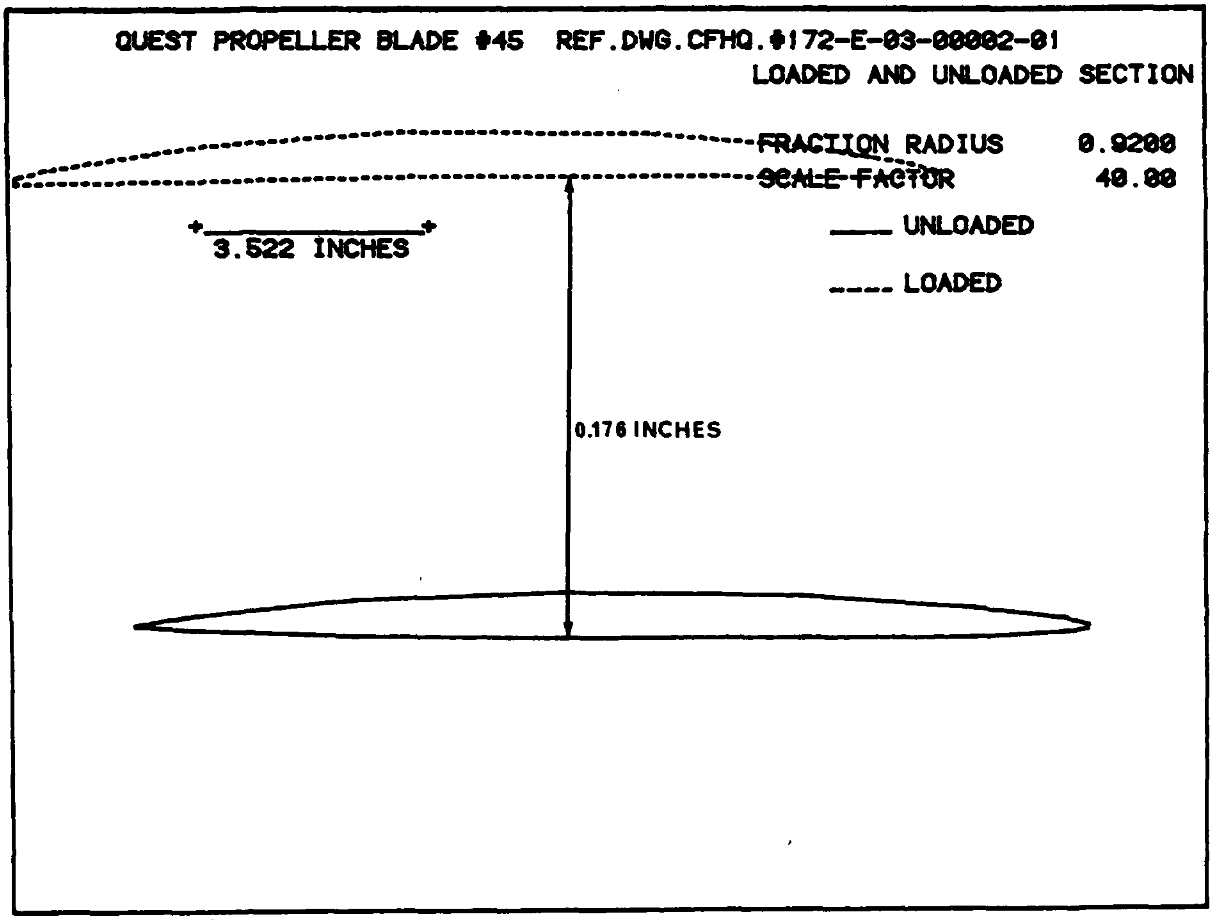


FIG. 66 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.92 FRACTION OF FULL RADIUS

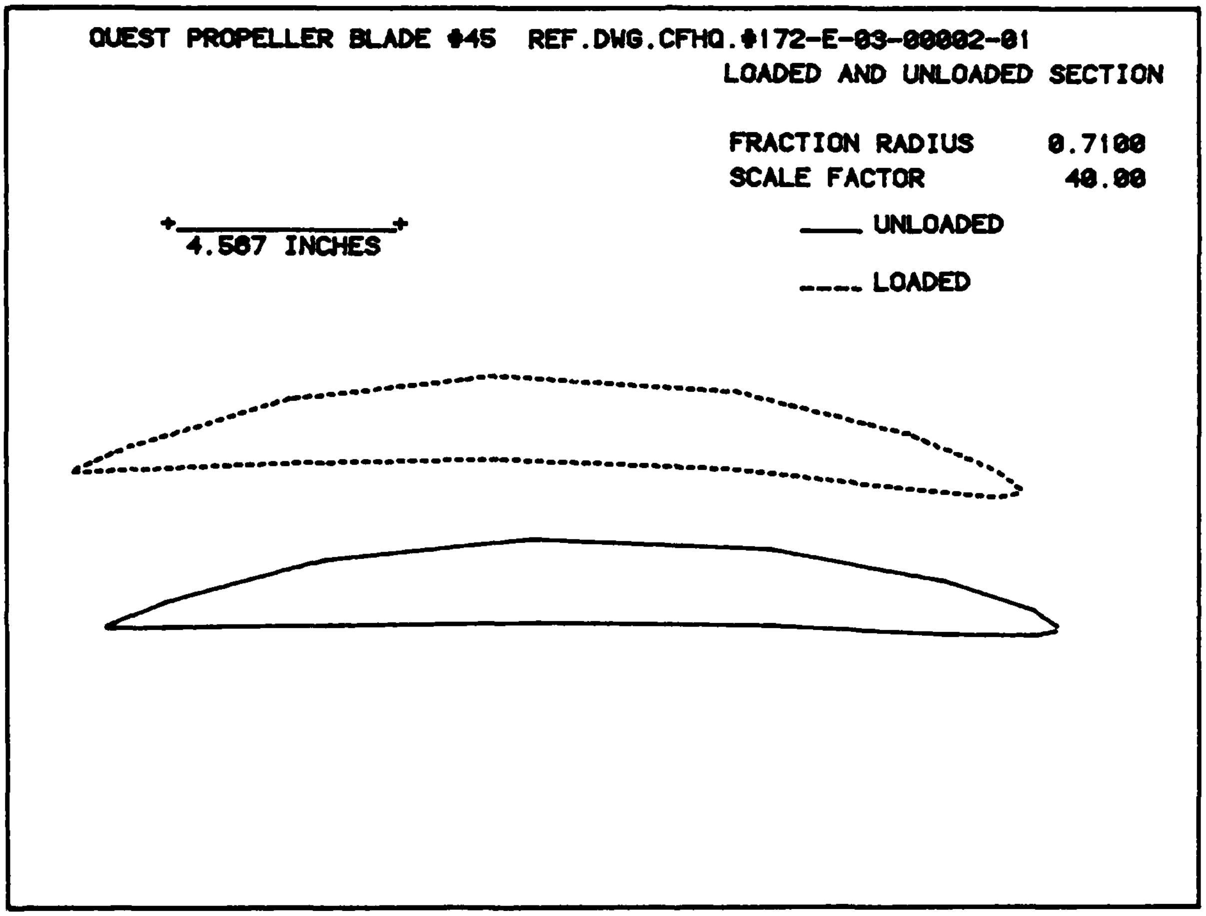


FIG. 65 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.71 FRACTION OF FULL RADIUS

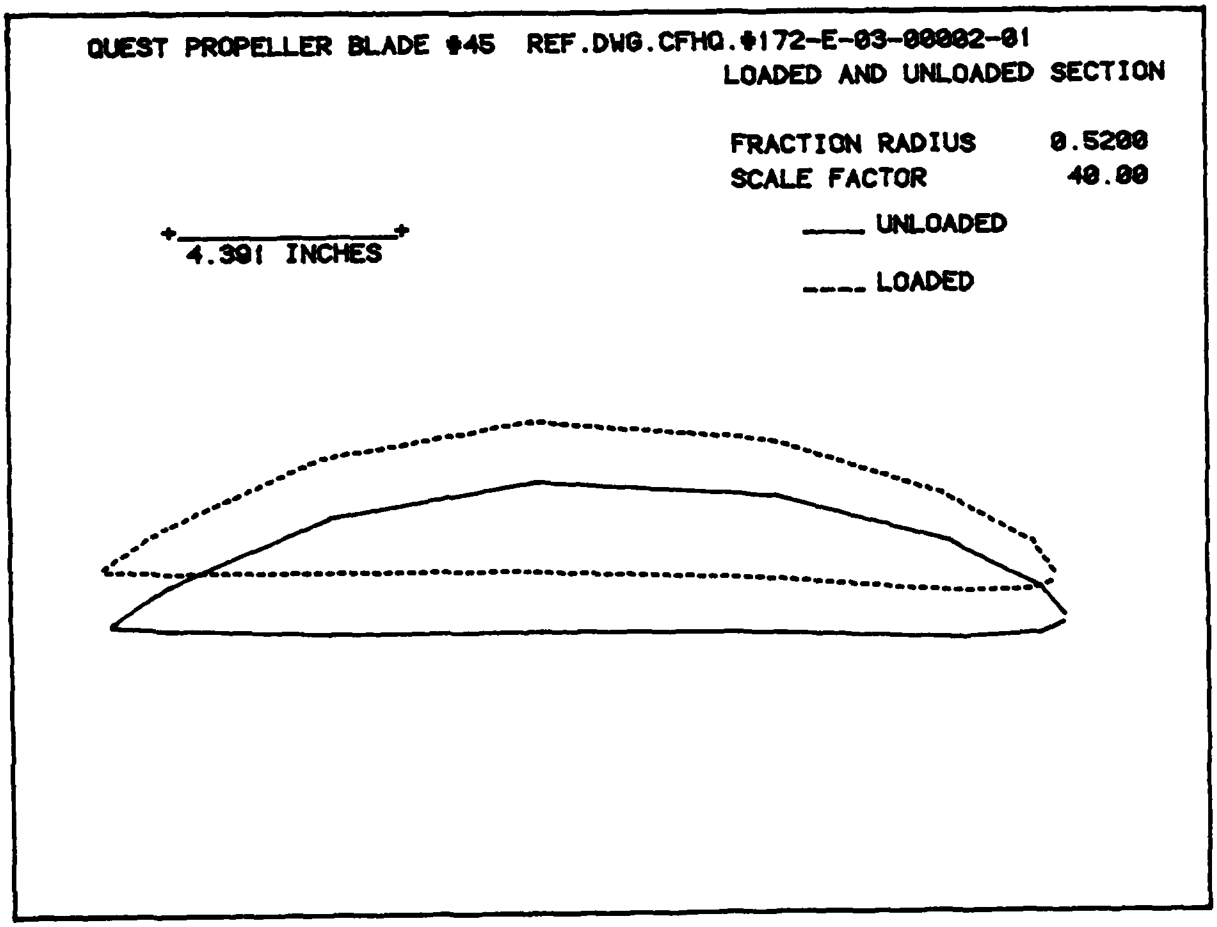


FIG. 64 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.52 FRACTION OF FULL RADIUS

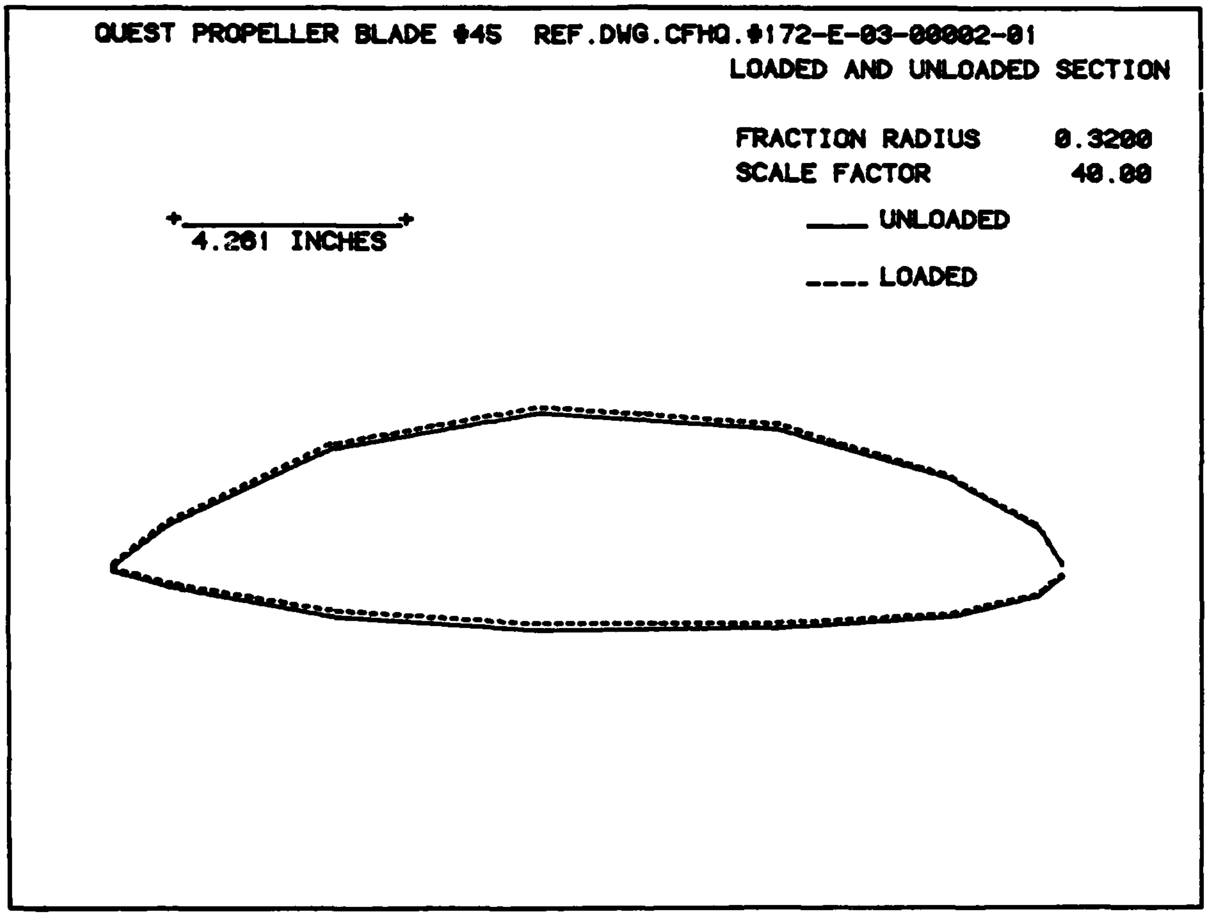


FIG. 63 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.32 FRACTION OF FULL RADIUS

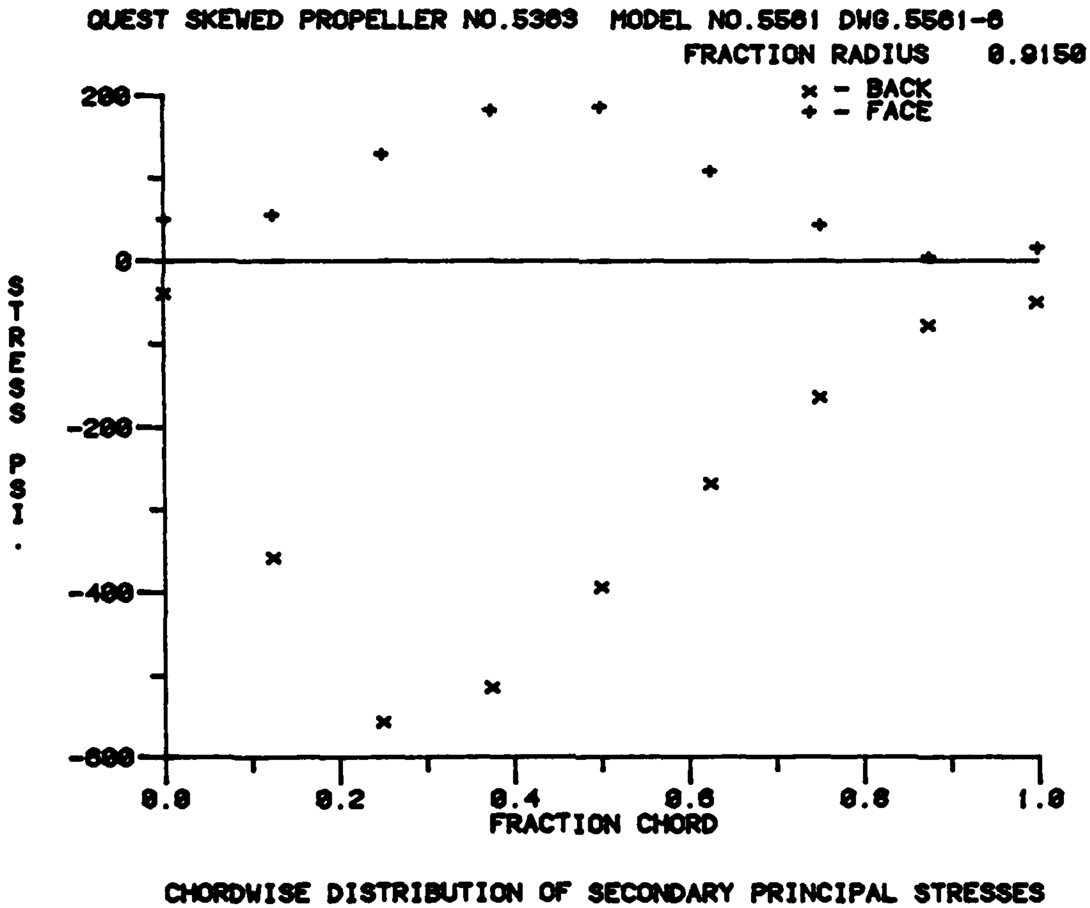


FIG. 62 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.92 FRACTION OF FULL RADIUS

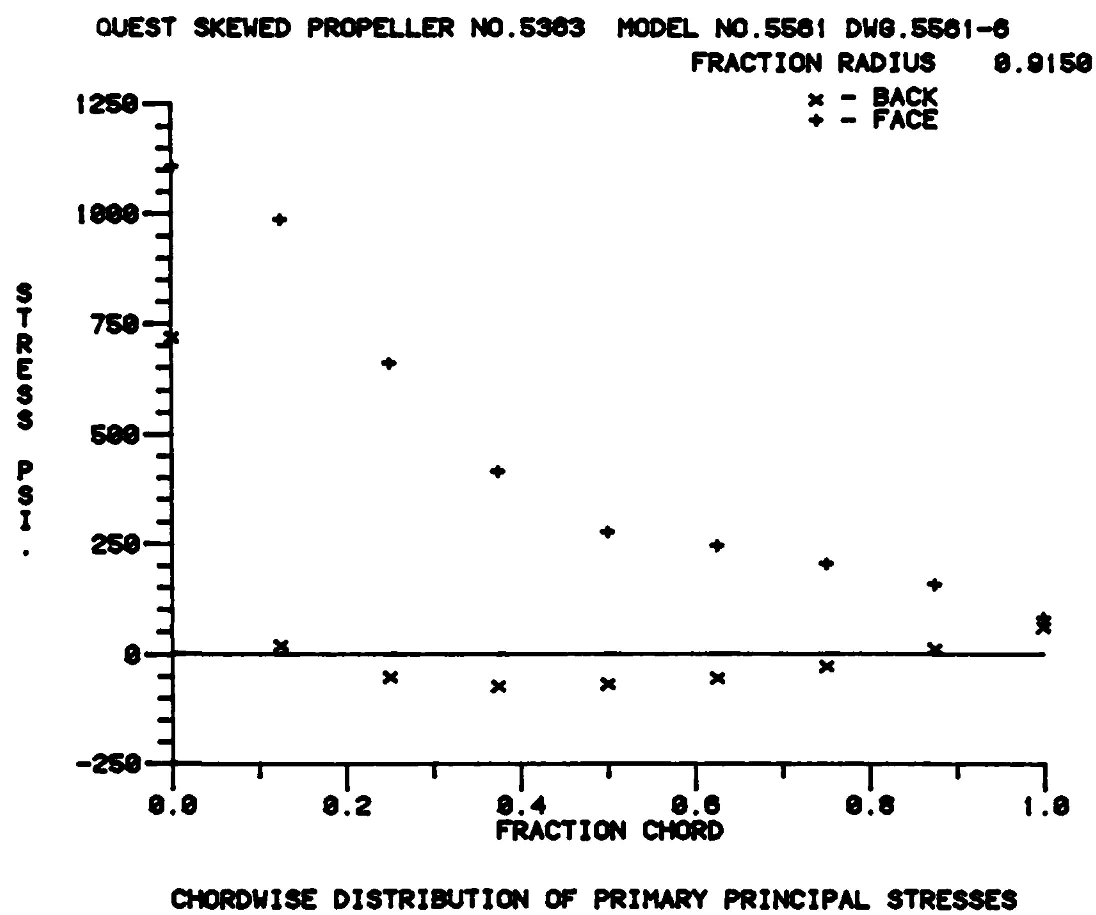


FIG. 61 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.92 FRACTION OF FULL RADIUS

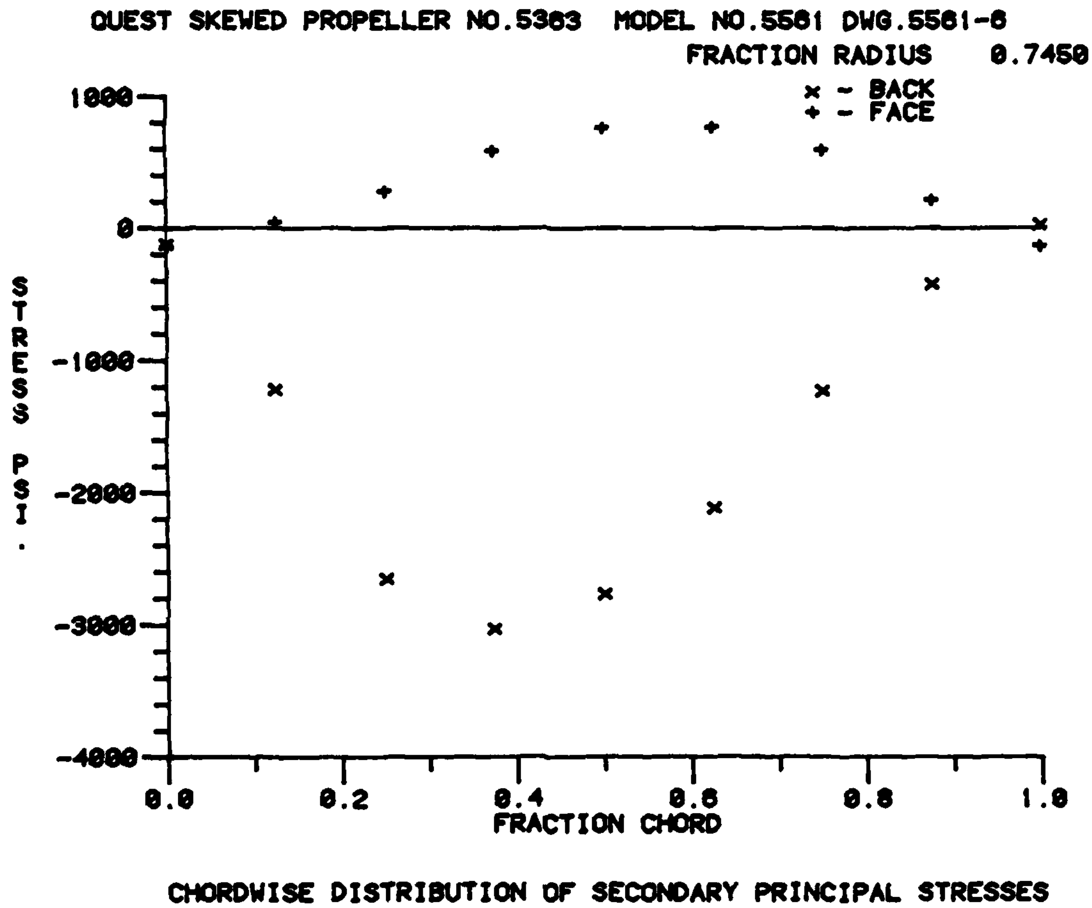


FIG. 60 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.75 FRACTION OF FULL RADIUS

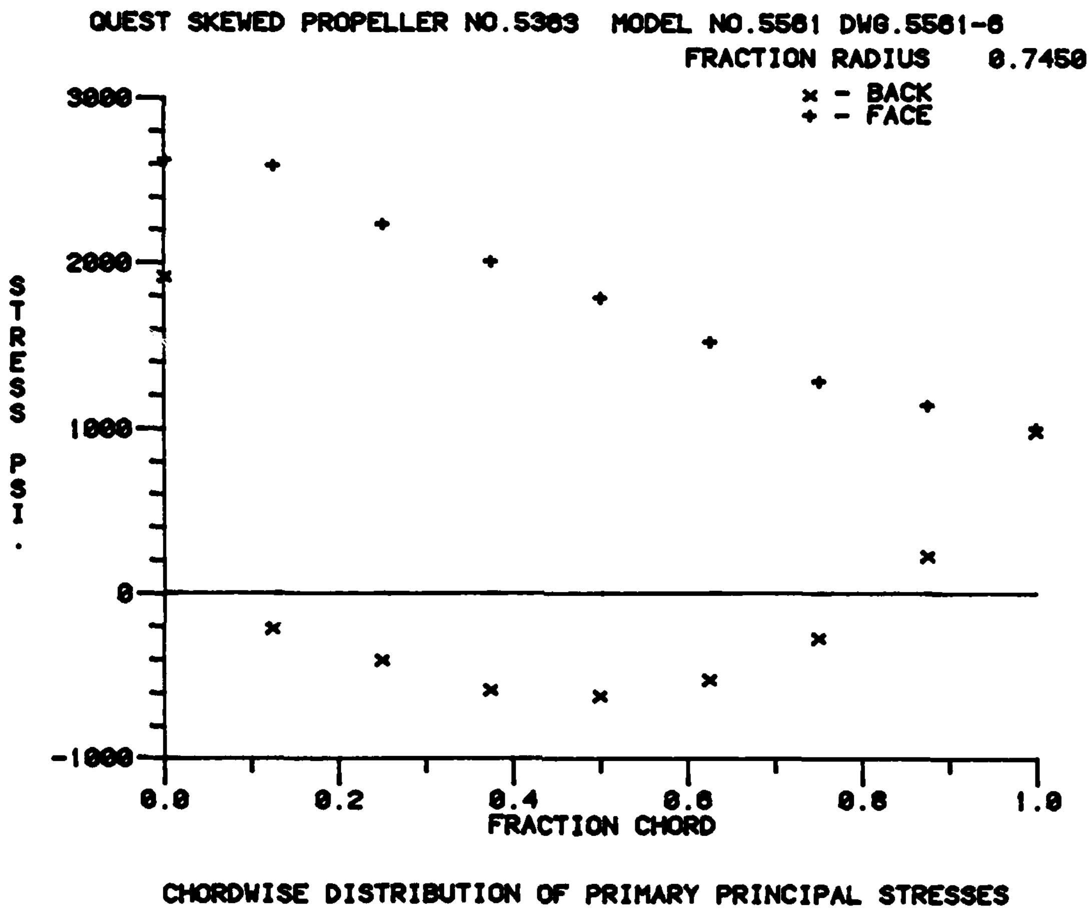


FIG. 59 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.75 FRACTION OF FULL RADIUS

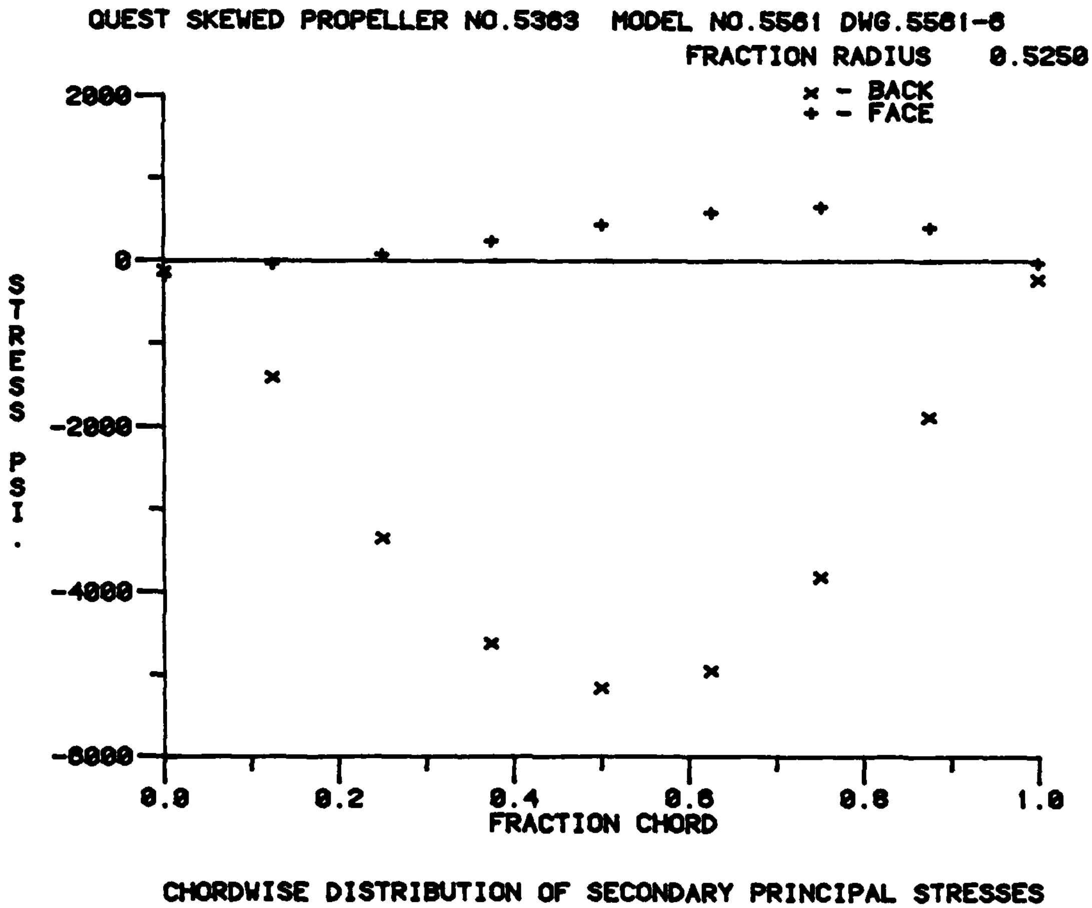


FIG. 58 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.53 FRACTION OF FULL RADIUS

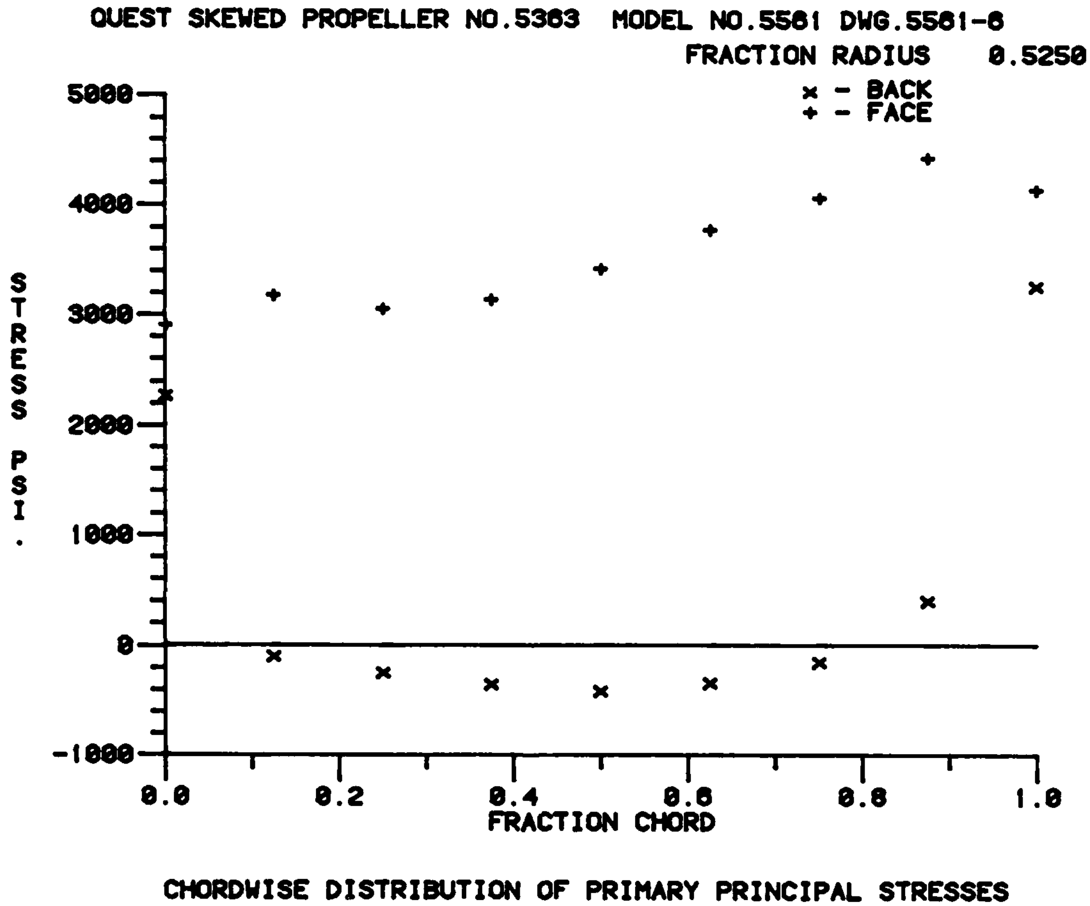


FIG. 57 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.53 FRACTION OF FULL RADIUS

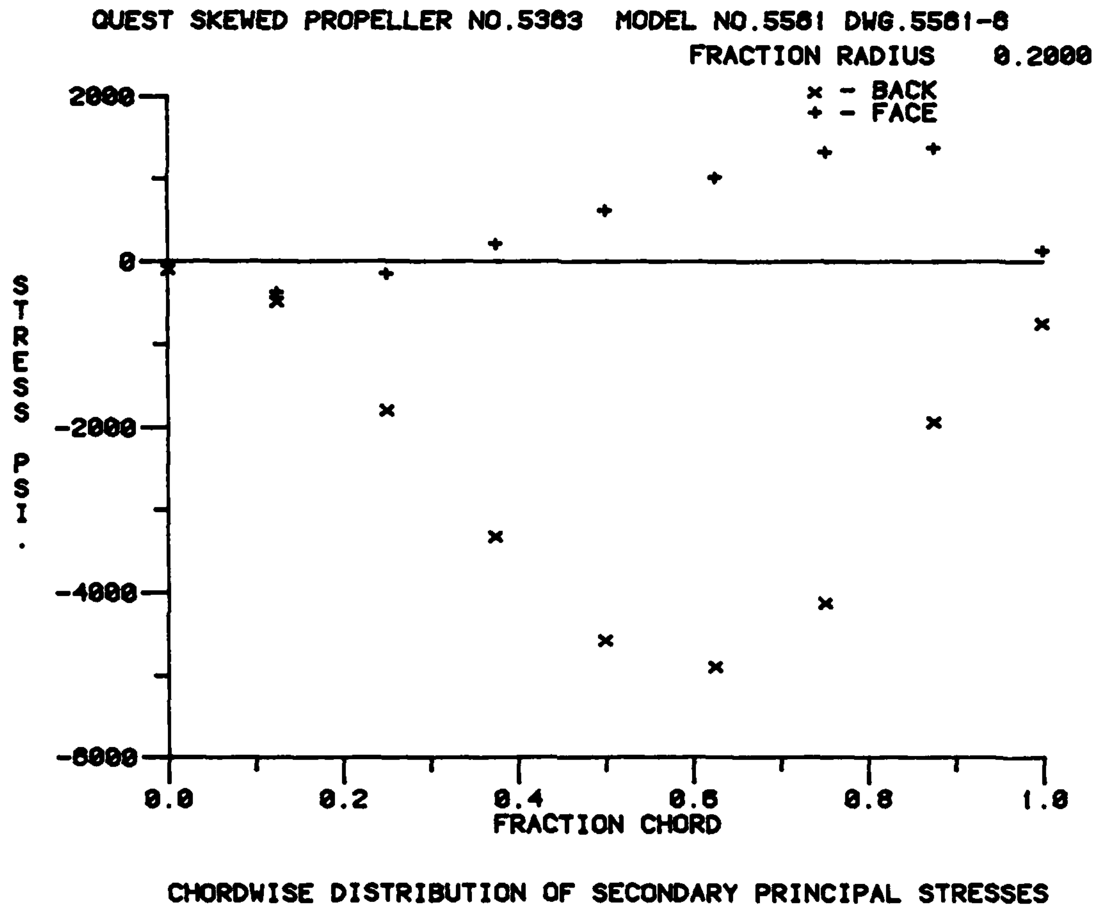


FIG. 56 CHORDWISE SECONDARY PRINCIPAL STRESS DISTRIBUTION AT 0.2 FRACTION OF FULL RADIUS

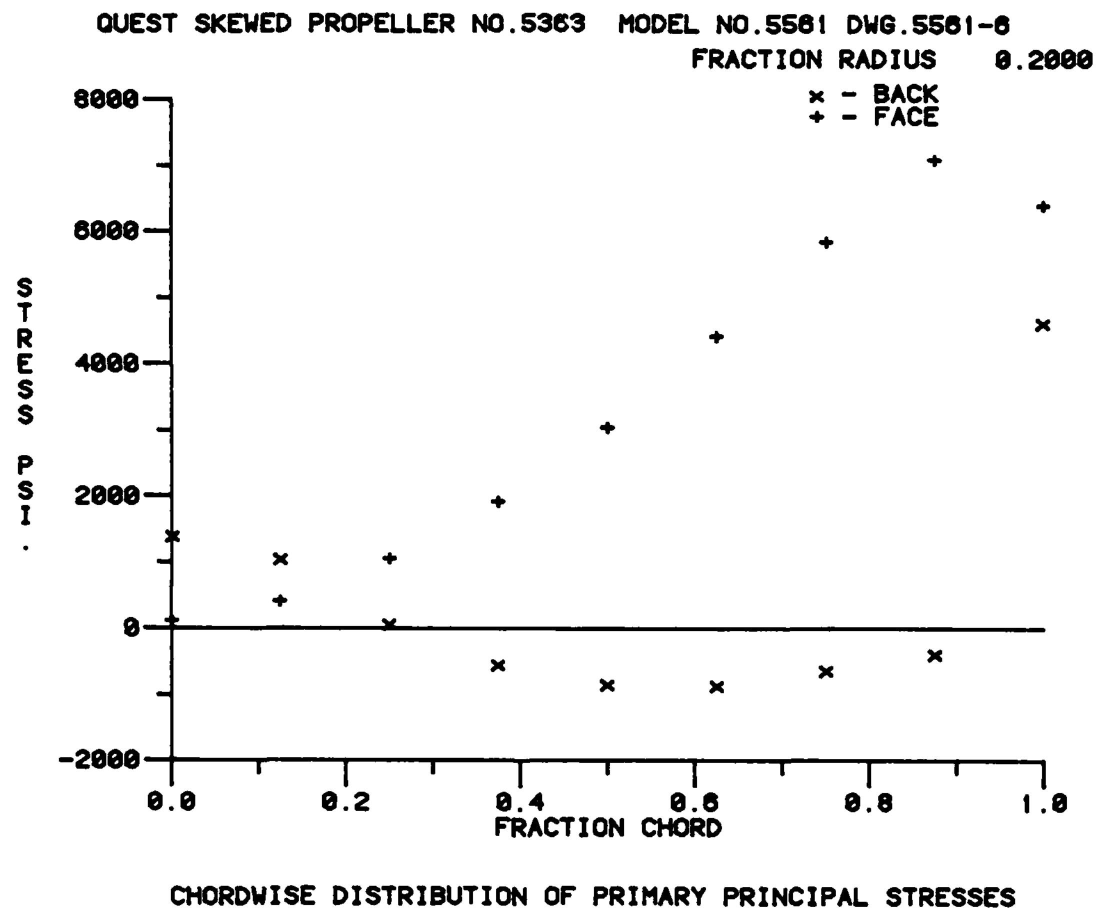


FIG. 55 CHORDWISE PRIMARY PRINCIPAL STRESS DISTRIBUTION AT 0.2 FRACTION OF FULL RADIUS

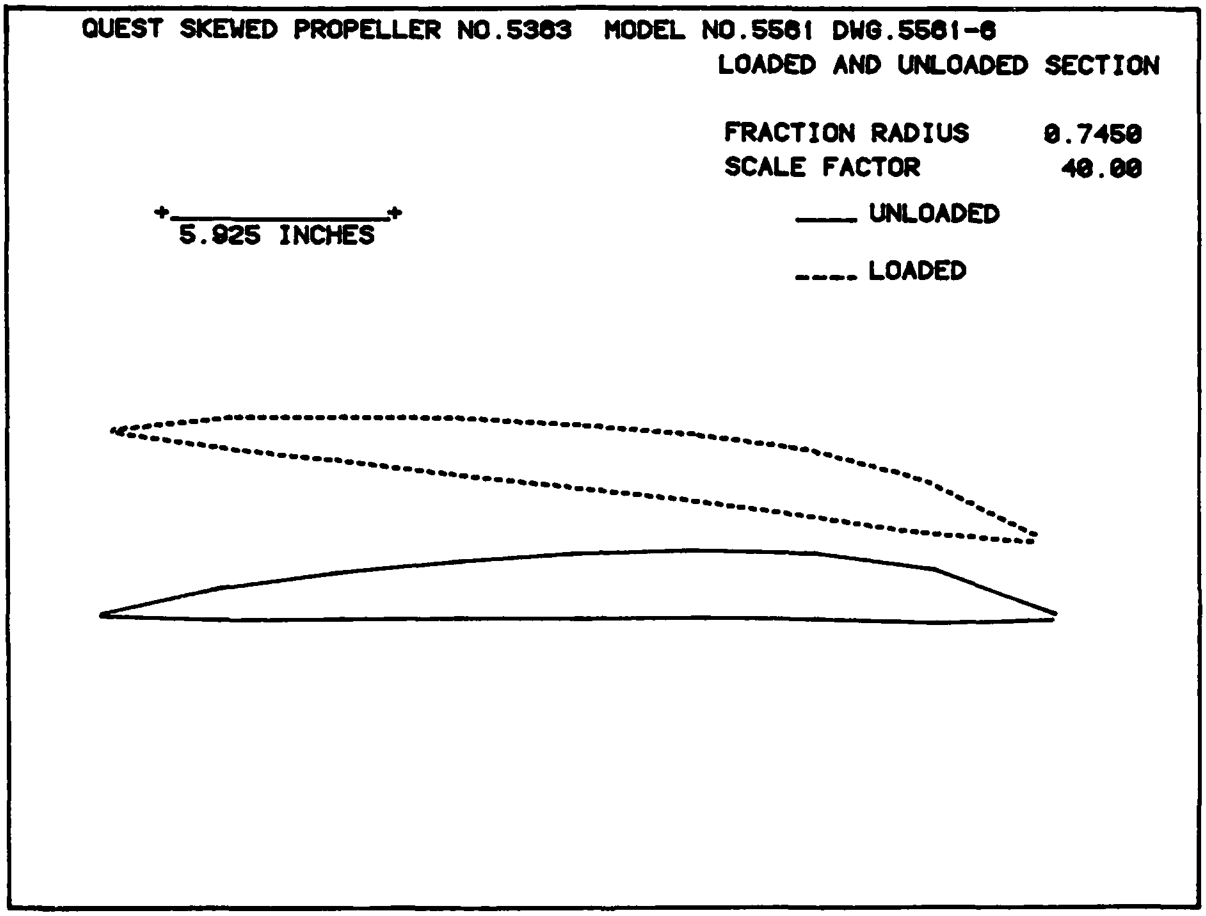


FIG. 69 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.75 FRACTION OF FULL RADIUS

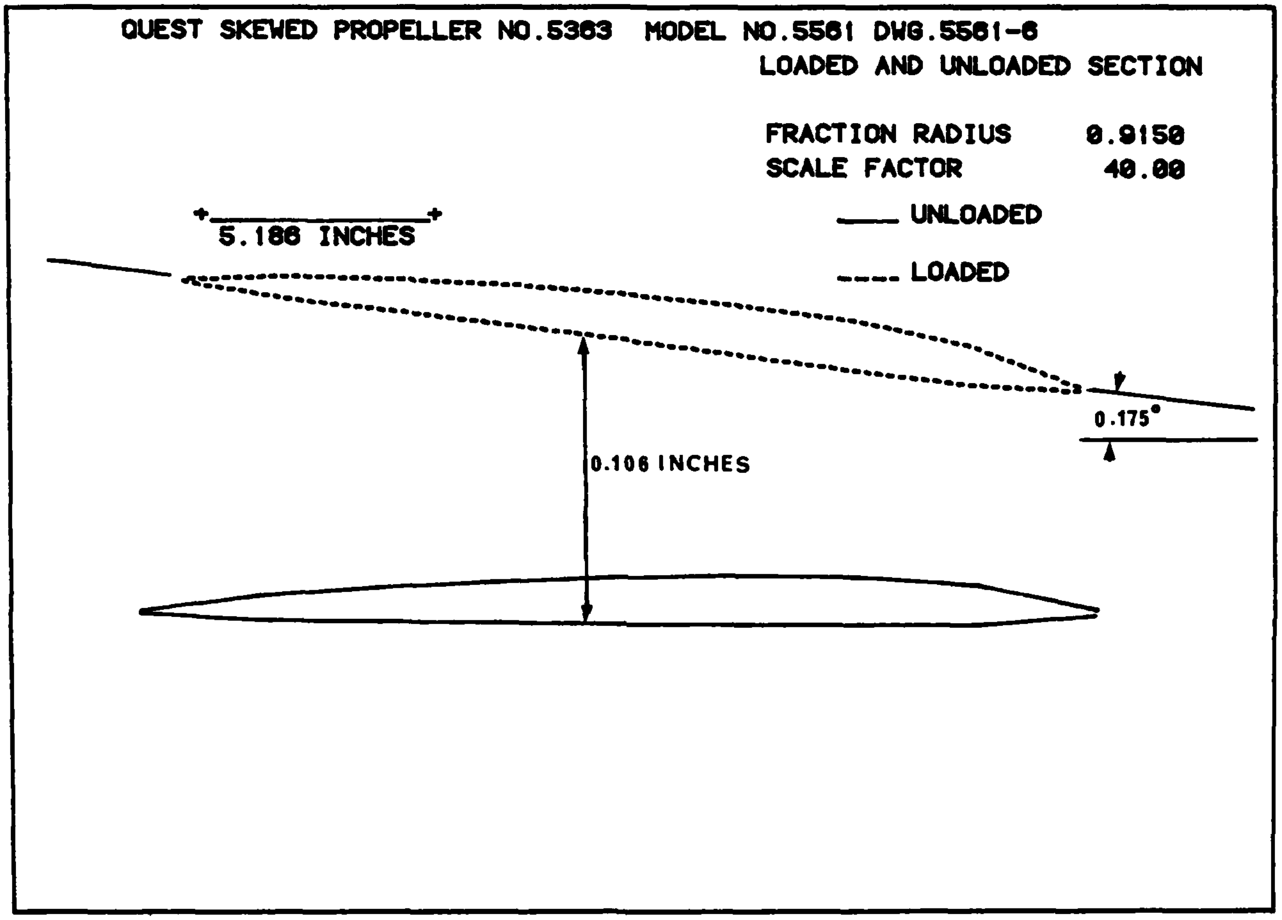


FIG. 70 STATIC DISTORTION OF FULLY DEVELOPED SECTION AT 0.92 FRACTION OF FULL RADIUS

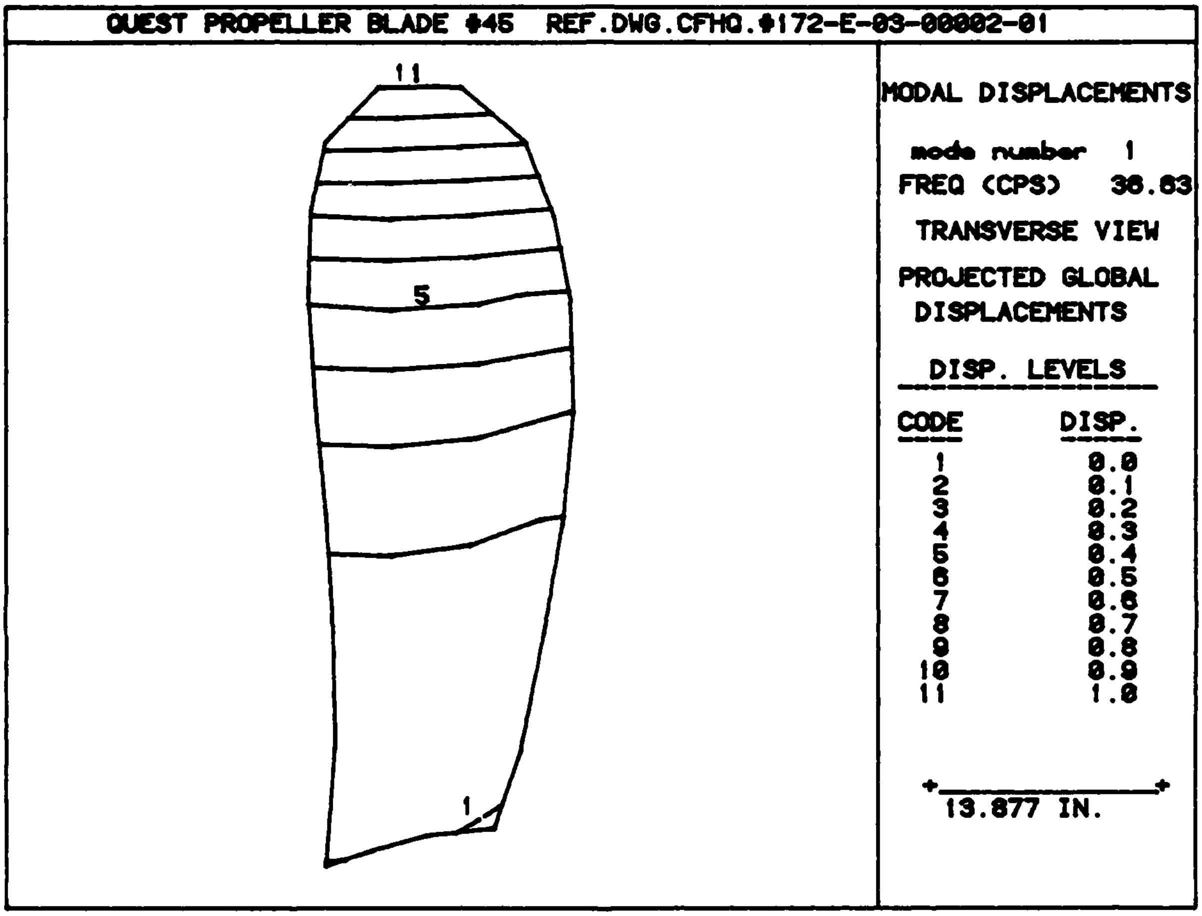


FIG. 71 NORMALIZED DISPLACEMENT CONTOURS OF THE 1ST NATURAL FREQUENCY OF VIBRATION IN WATER

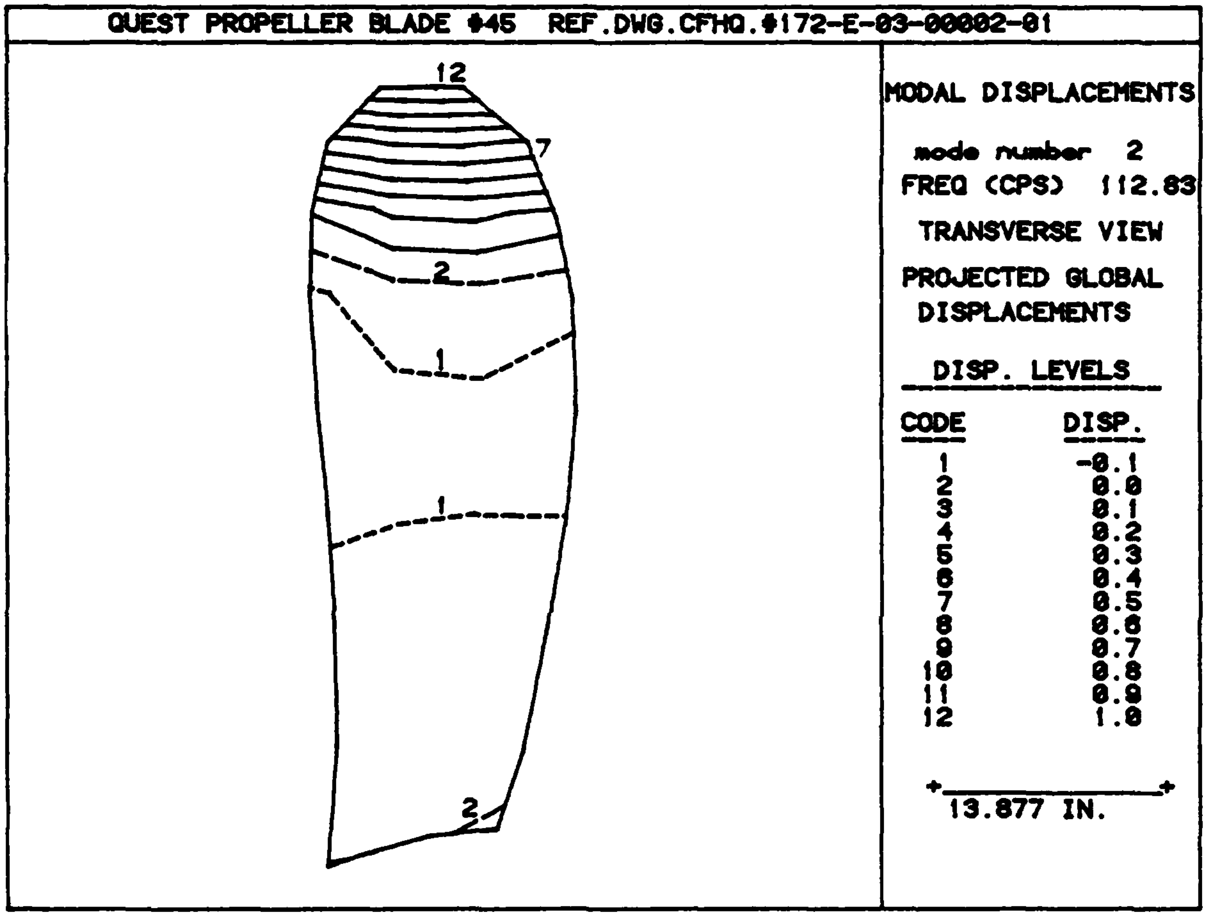


FIG. 72 NORMALIZED DISPLACEMENT CONTOURS OF THE 2ND NATURAL FREQUENCY OF VIBRATION IN WATER

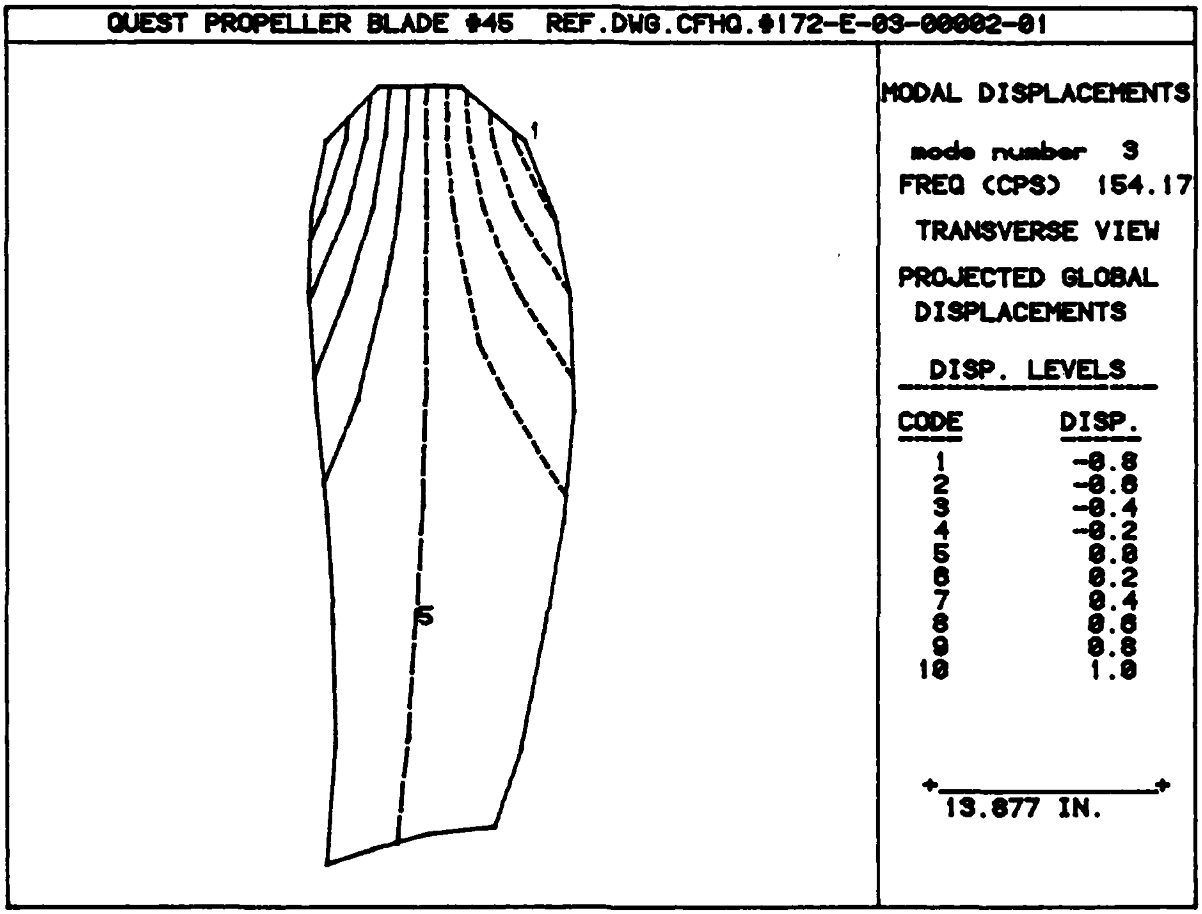


FIG. 73 NORMALIZED DISPLACEMENT CONTOURS OF THE 3RD NATURAL FREQUENCY OF VIBRATION IN WATER

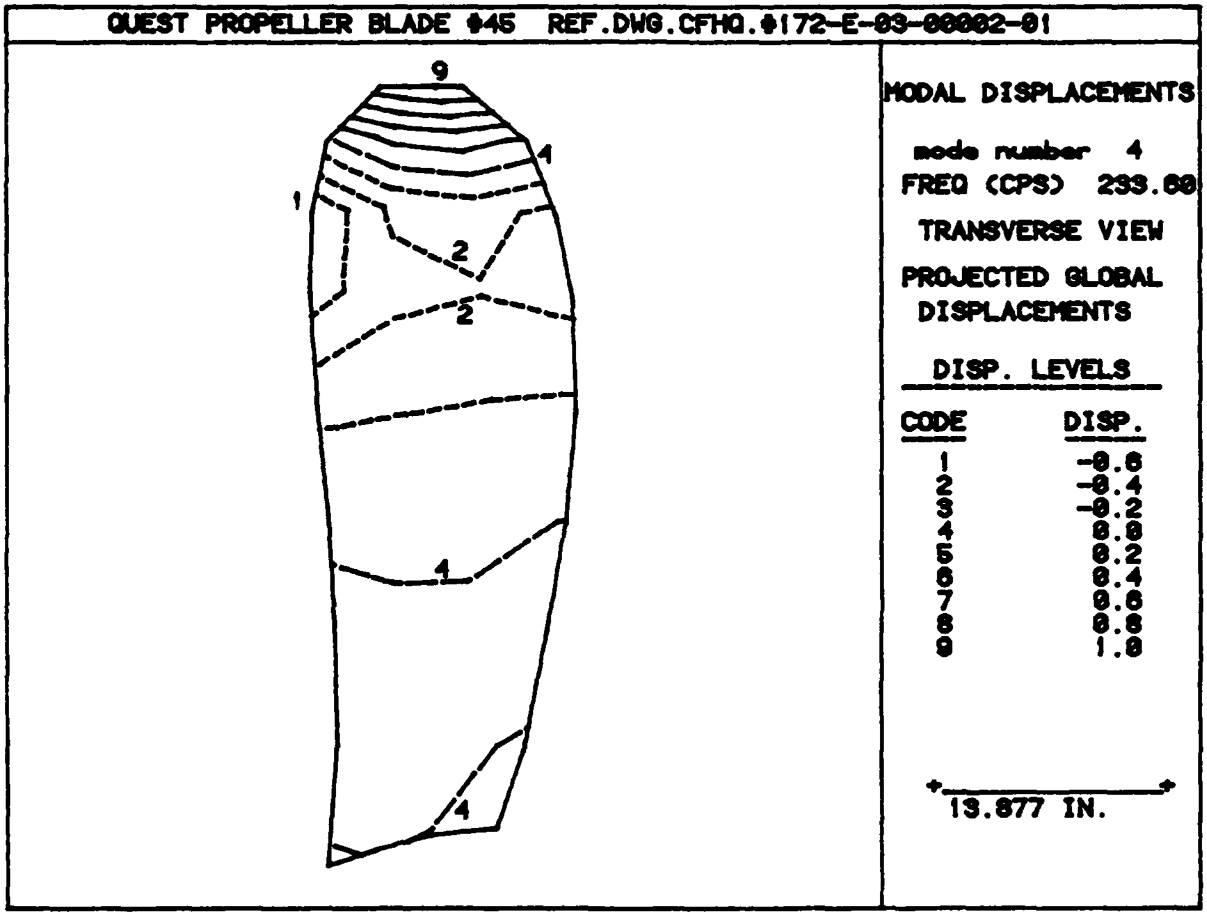


FIG. 74 NORMALIZED DISPLACEMENT CONTOURS OF THE 4TH NATURAL FREQUENCY OF VIBRATION IN WATER

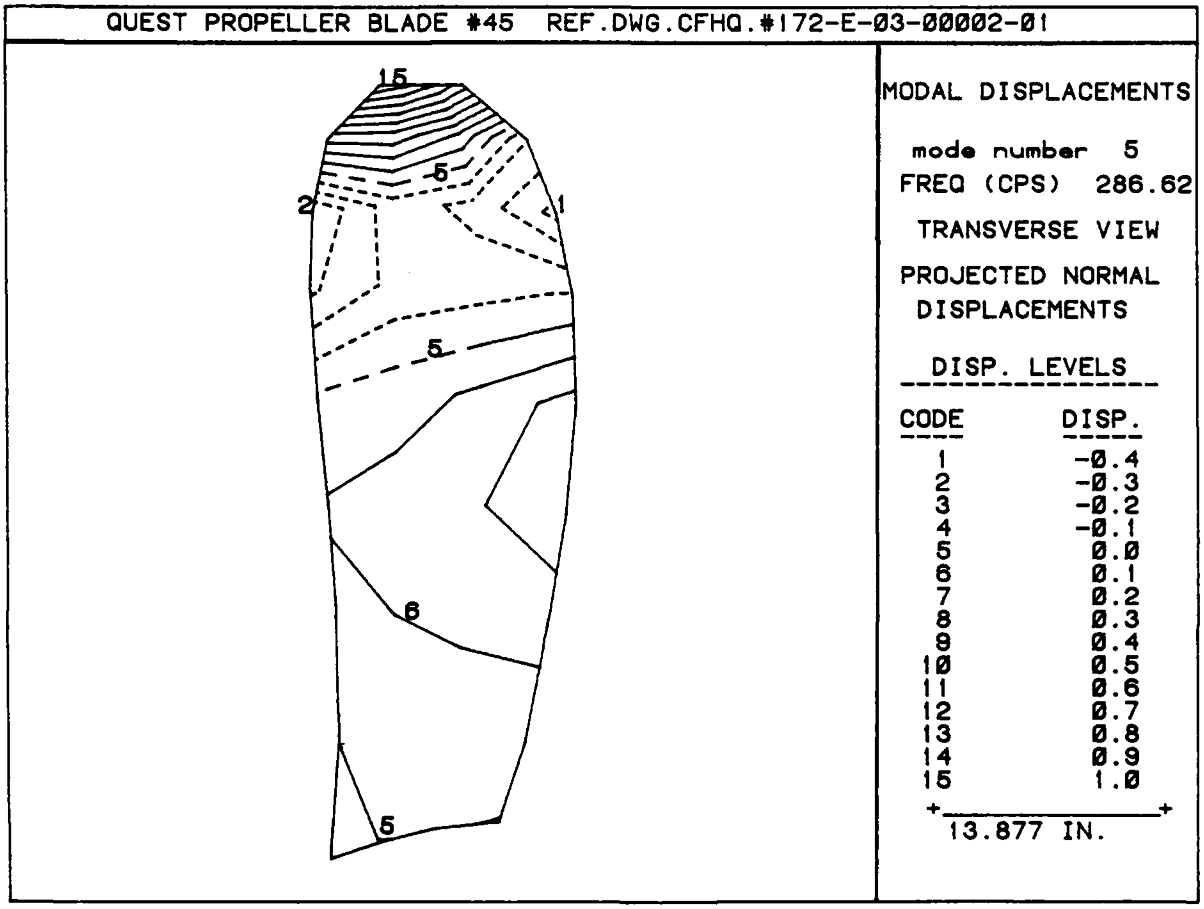


FIG. 75 NORMALIZED DISPLACEMENT CONTOURS OF THE 5TH NATURAL FREQUENCY OF VIBRATION IN WATER

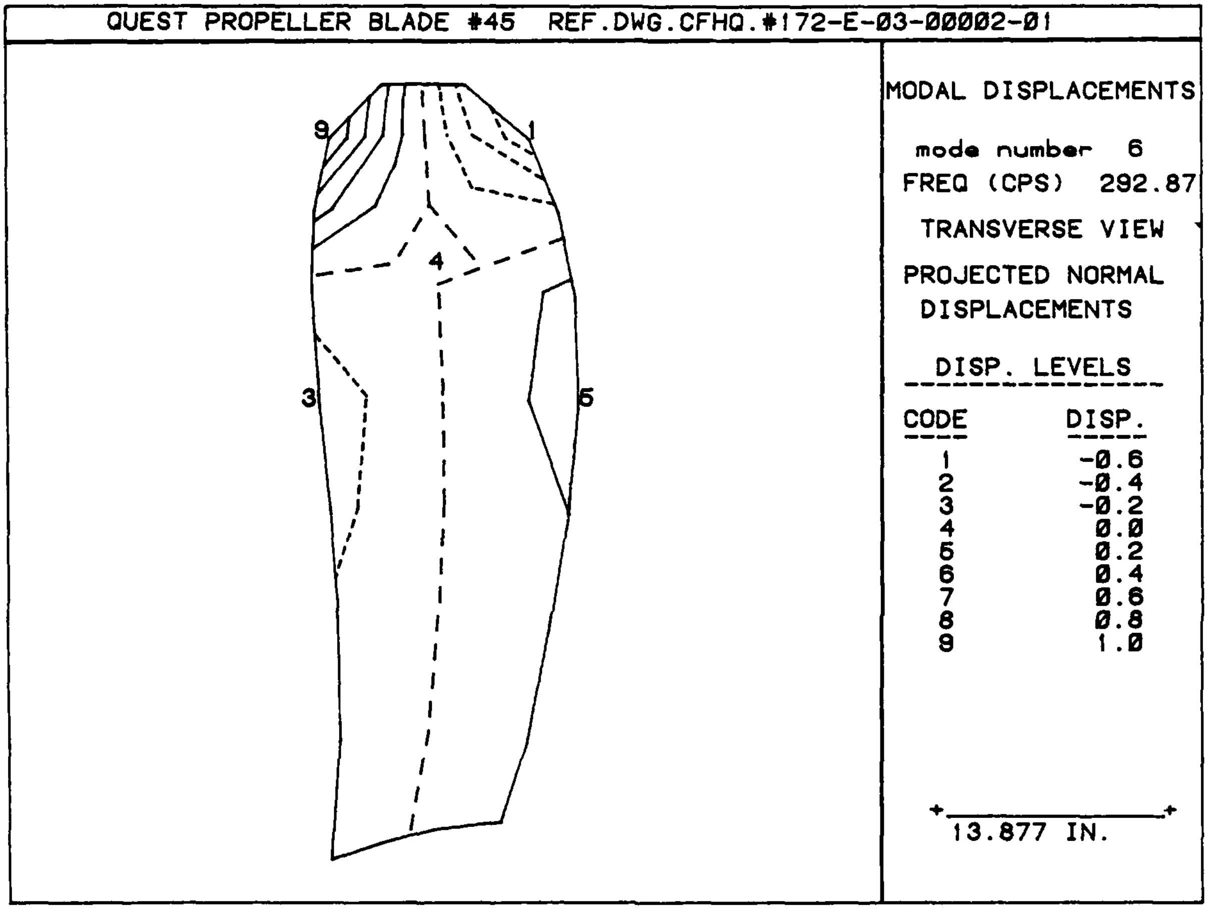


FIG. 76 NORMALIZED DISPLACEMENT CONTOURS OF THE 6TH NATURAL FREQUENCY OF VIBRATION IN WATER

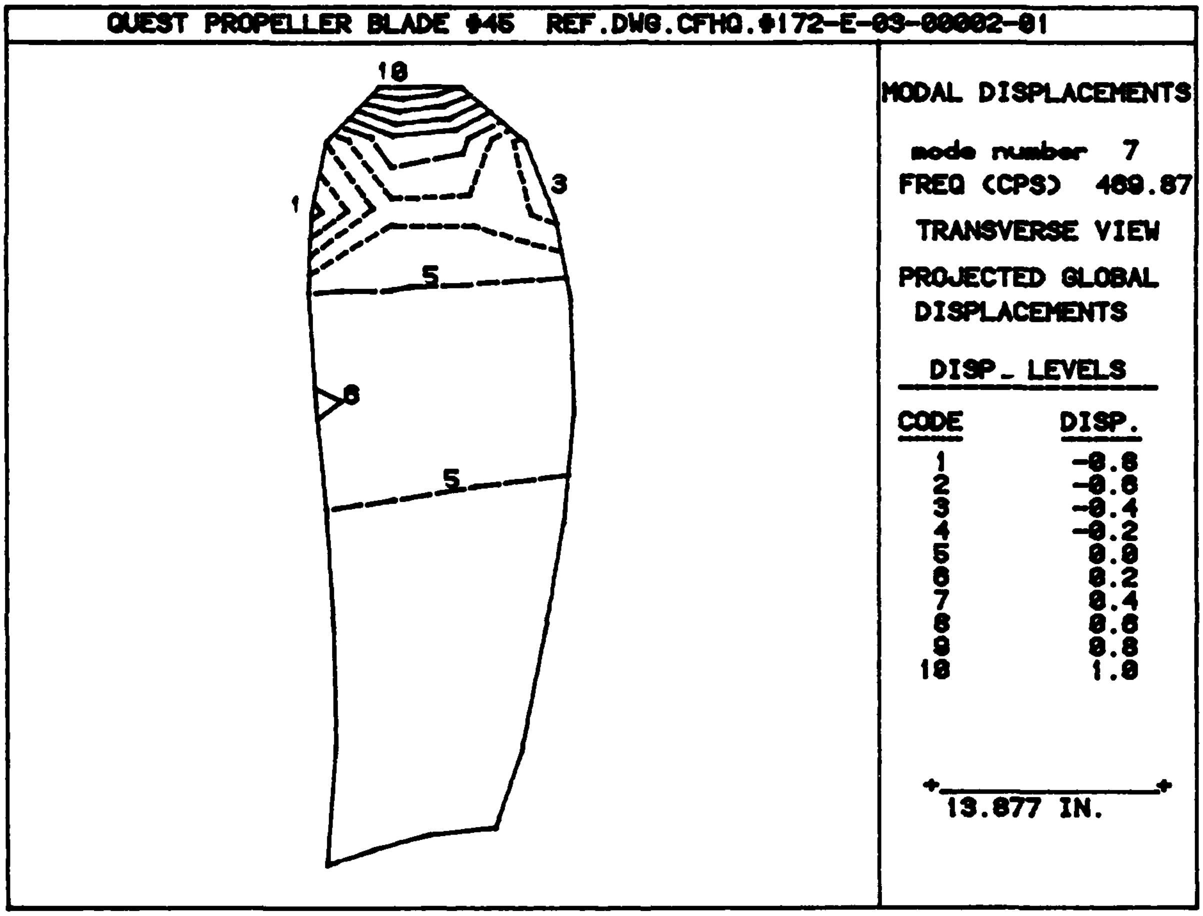


FIG. 77 NORMALIZED DISPLACEMENT CONTOURS OF THE 7TH NATURAL FREQUENCY OF VIBRATION IN WATER

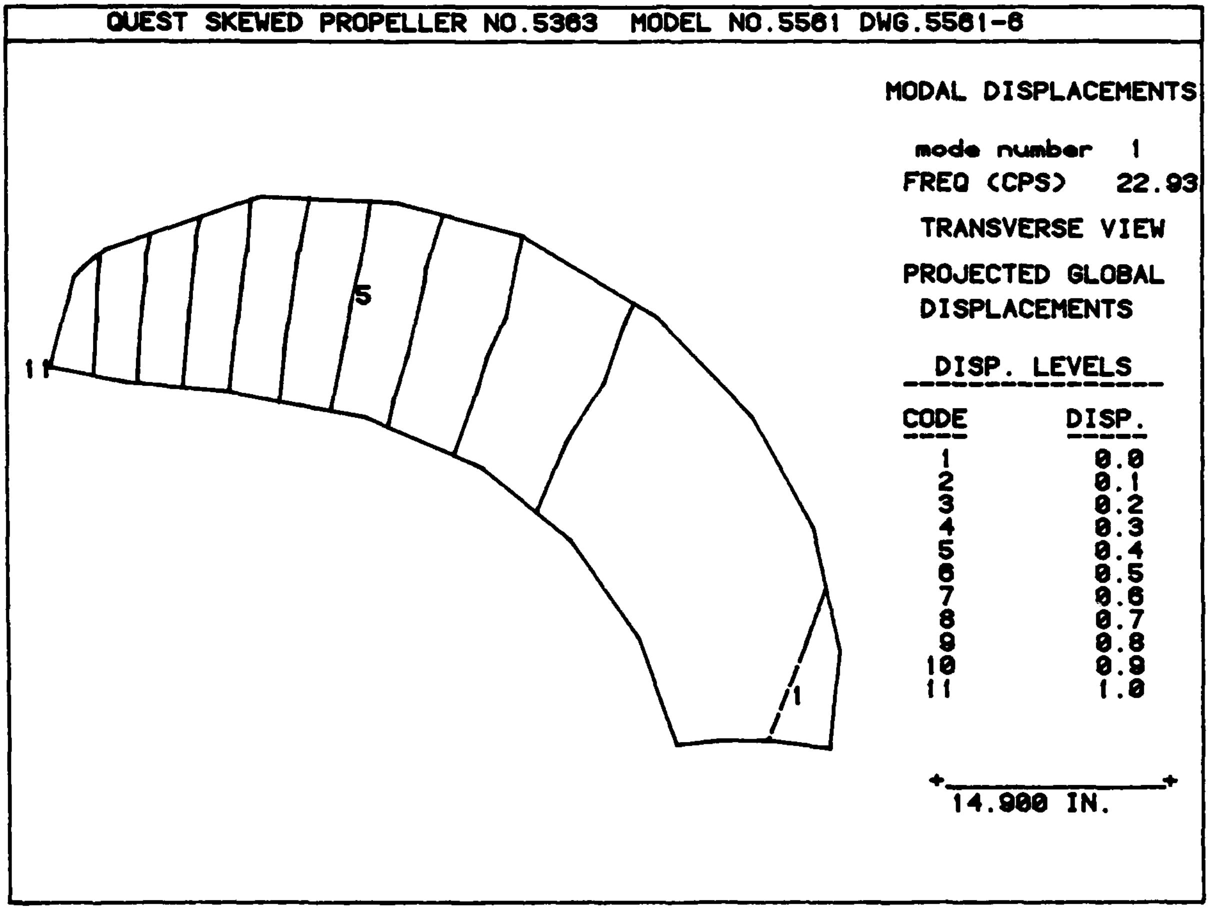


FIG. 78 NORMALIZED DISPLACEMENT CONTOURS OF THE 1ST NATURAL FREQUENCY OF VIBRATION IN WATER

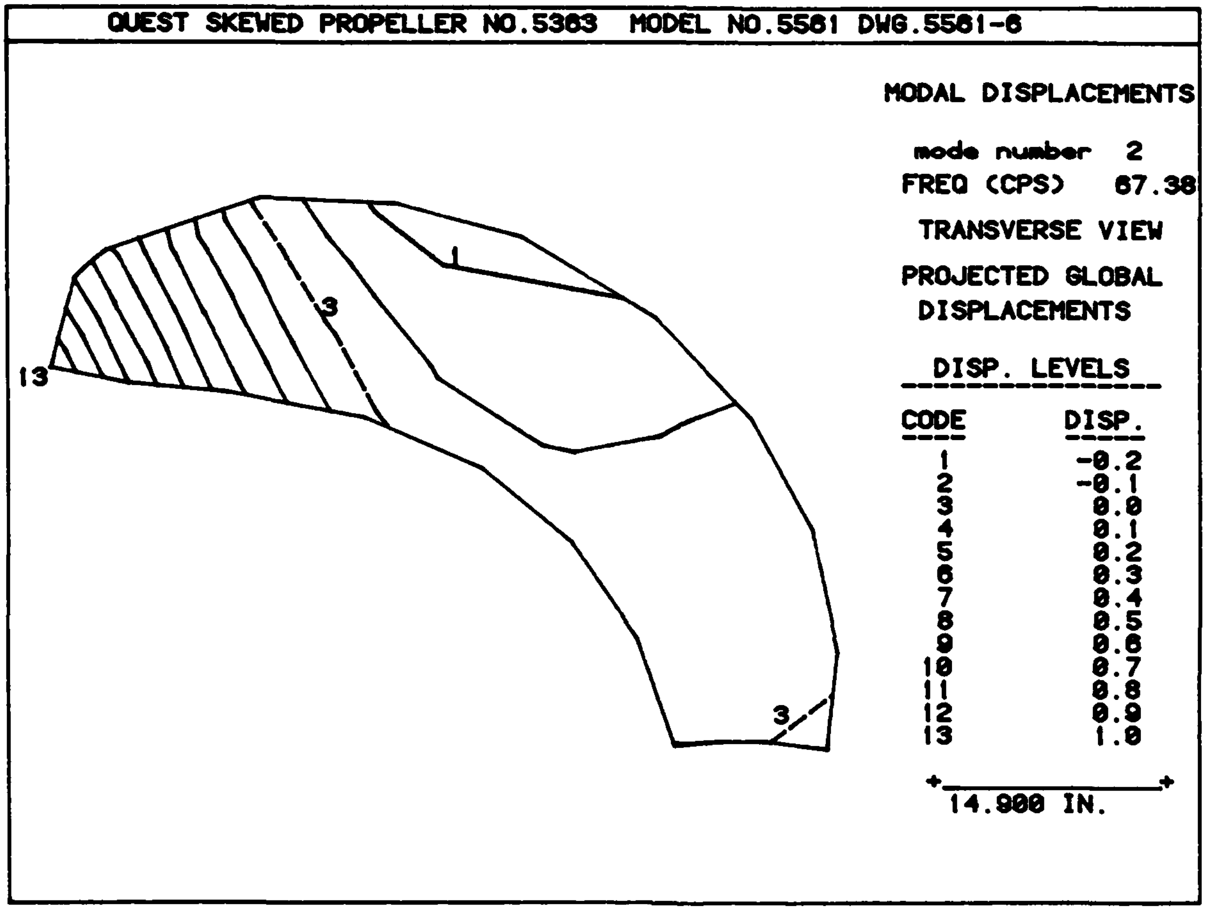


FIG. 79 NORMALIZED DISPLACEMENT CONTOURS OF THE 2ND NATURAL FREQUENCY OF VIBRATION IN WATER

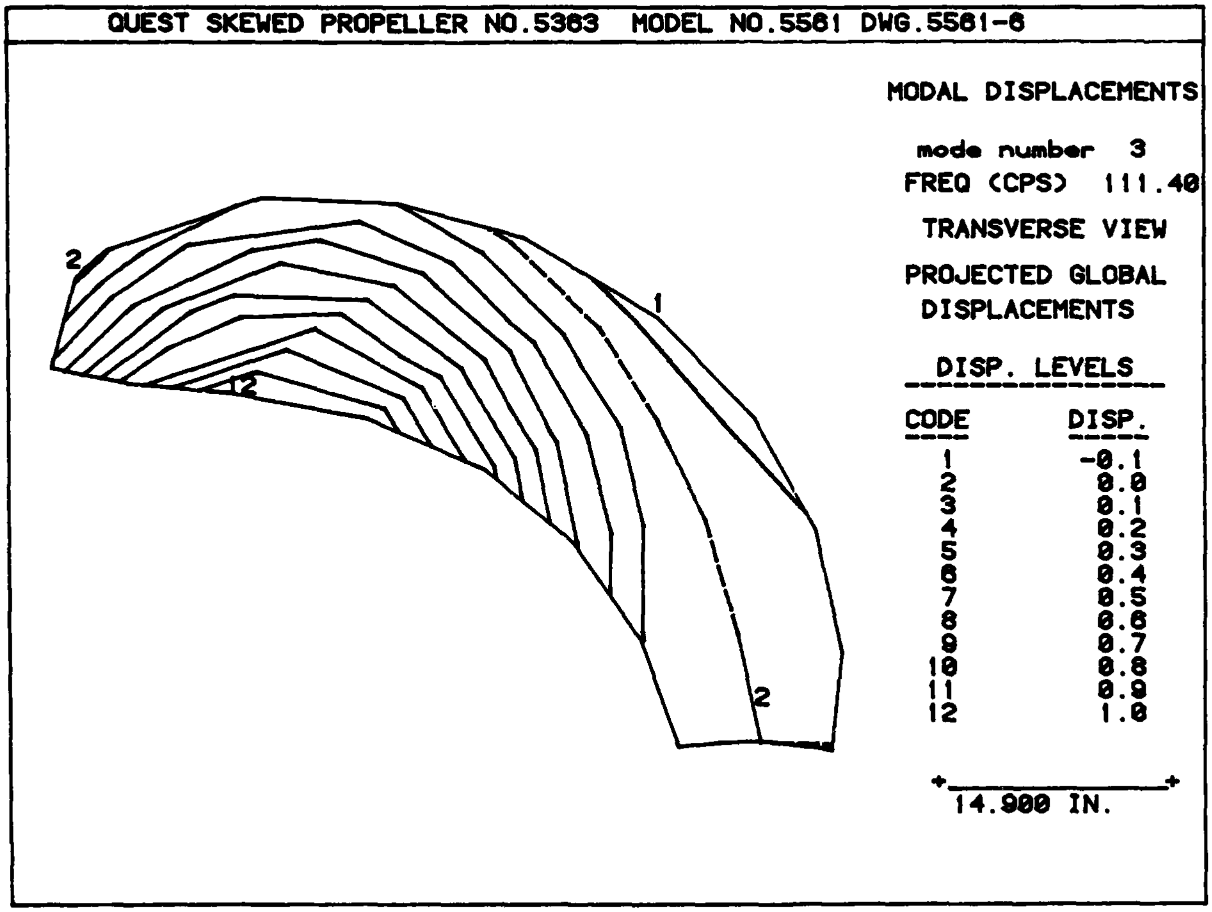


FIG. 80 NORMALIZED DISPLACEMENT CONTOURS OF THE 3RD NATURAL FREQUENCY OF VIBRATION IN WATER

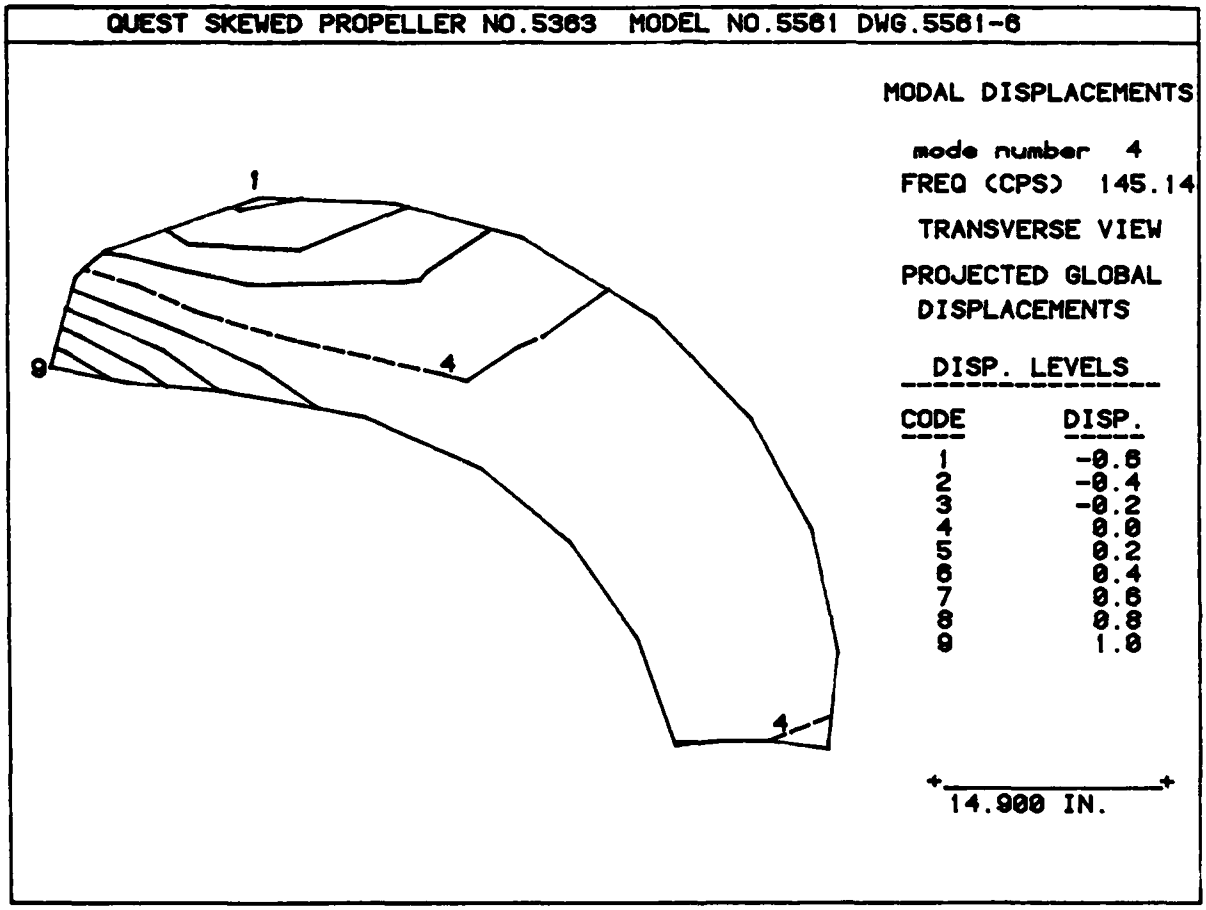


FIG. 81 NORMALIZED DISPLACEMENT CONTOURS OF THE 4TH NATURAL FREQUENCY OF VIBRATION IN WATER

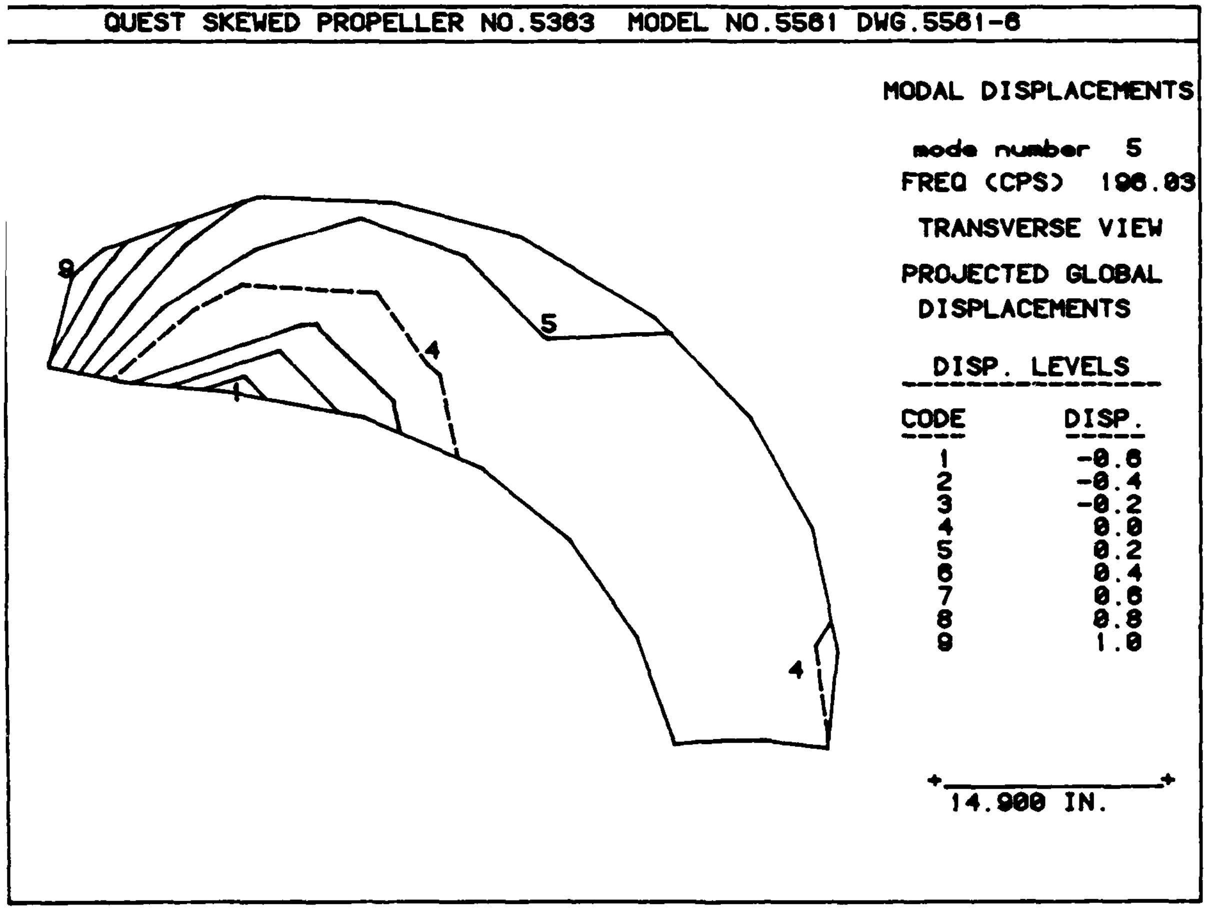


FIG. 82 NORMALIZED DISPLACEMENTS OF THE 5TH NATURAL FREQUENCY OF VIBRATION IN WATER

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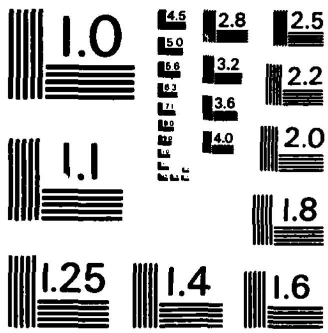
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4.5
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6.3
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1.1
1.8
1.25
1.4
1.6

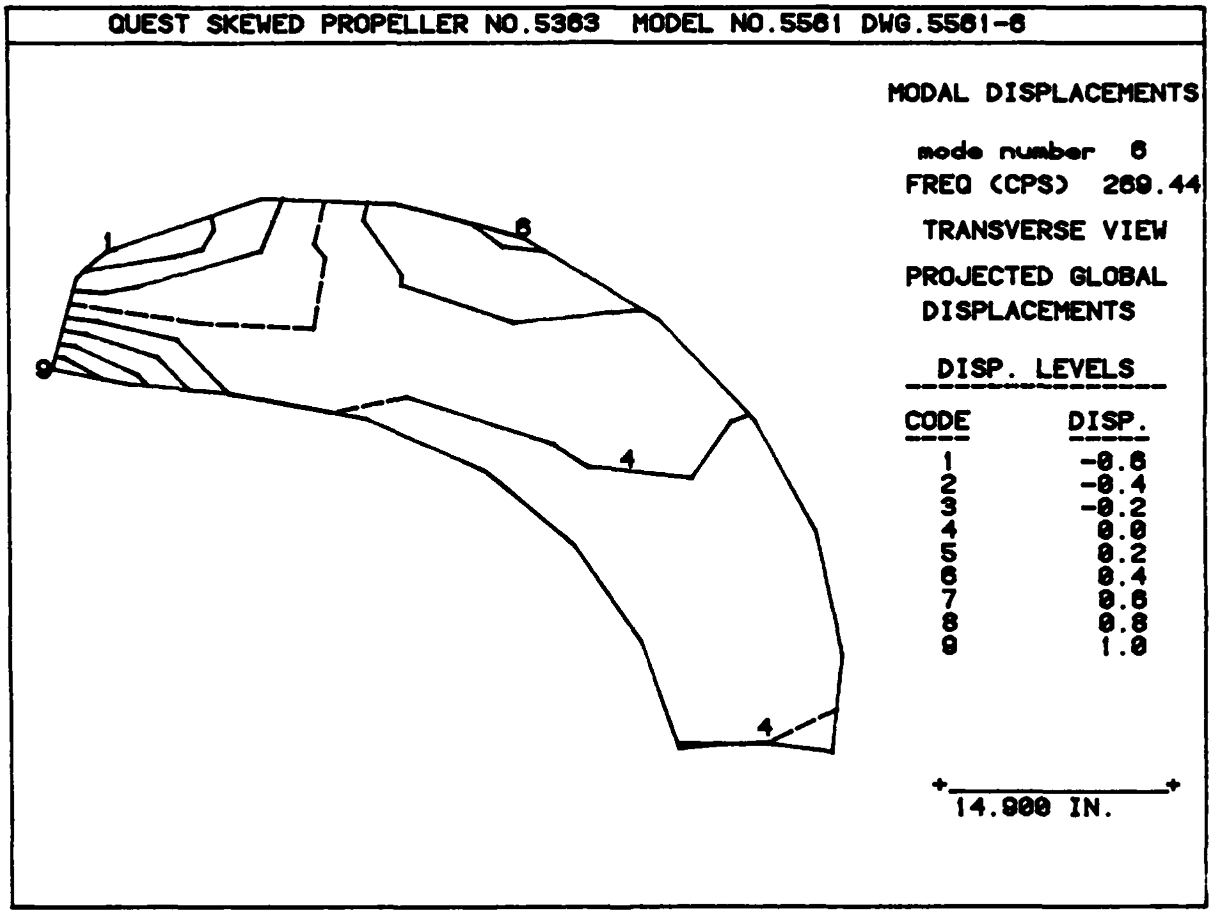

FIG. 83 NORMALIZED DISPLACEMENTS OF THE 6TH NATURAL FREQUENCY OF VIBRATION IN WATER

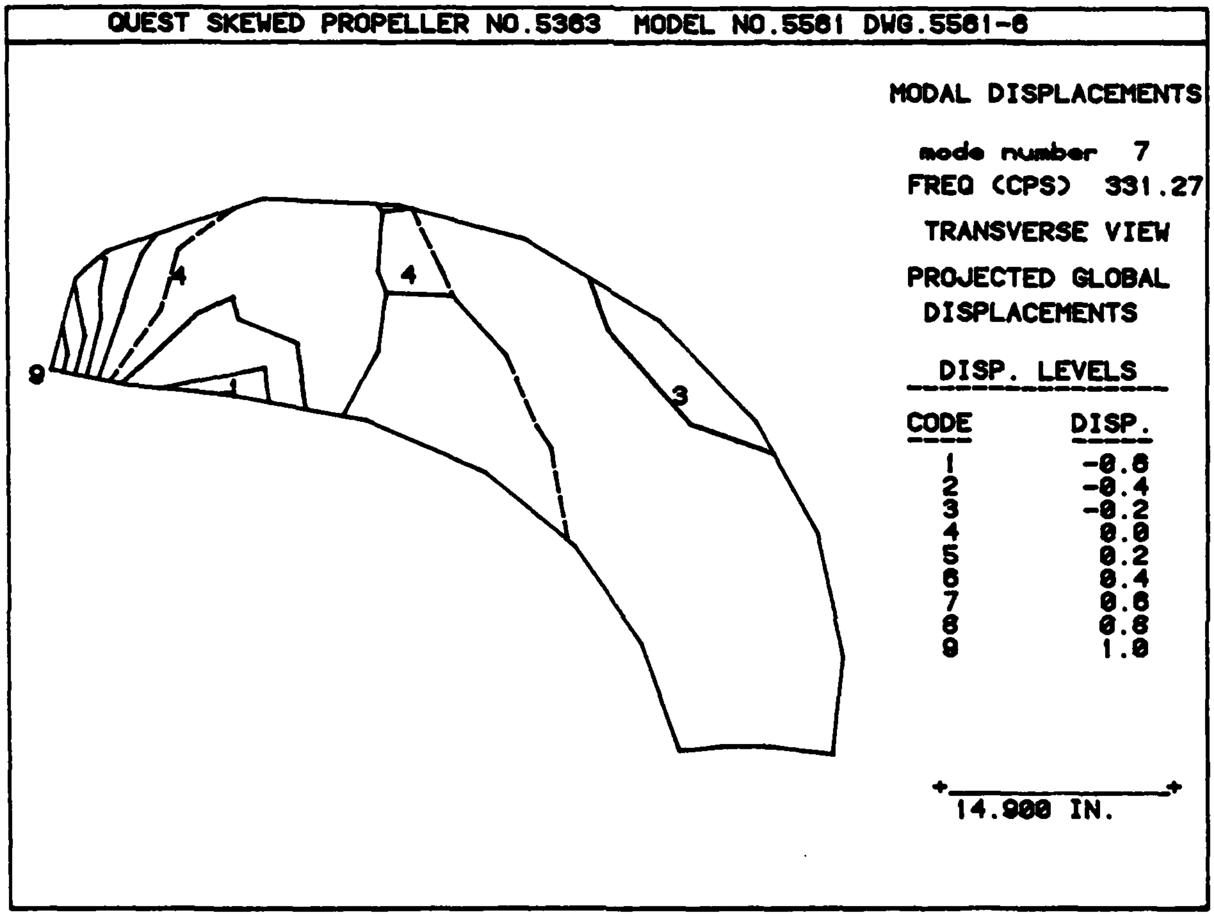

FIG. 84 NORMALIZED DISPLACEMENTS OF THE 7TH NATURAL FREQUENCY OF VIBRATION IN WATER

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13. ABSTRACT

The strength and vibration characteristics of the original NRC 45 and the new NSMB 5363 propellers for CFAV QUEST are predicted using the Finite Element Program PVAST. The static blade loadings for the analysis were produced with the M.I.T. Program PINV 4. Predictions are presented for stresses, static displacements, and natural frequencies of vibration for both propellers. Static stress results obtained using PVAST are shown to be in good agreement with those supplied by the Netherlands Ship Model Basin for the NSMB 5363 propellers.

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KEY WORDS

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